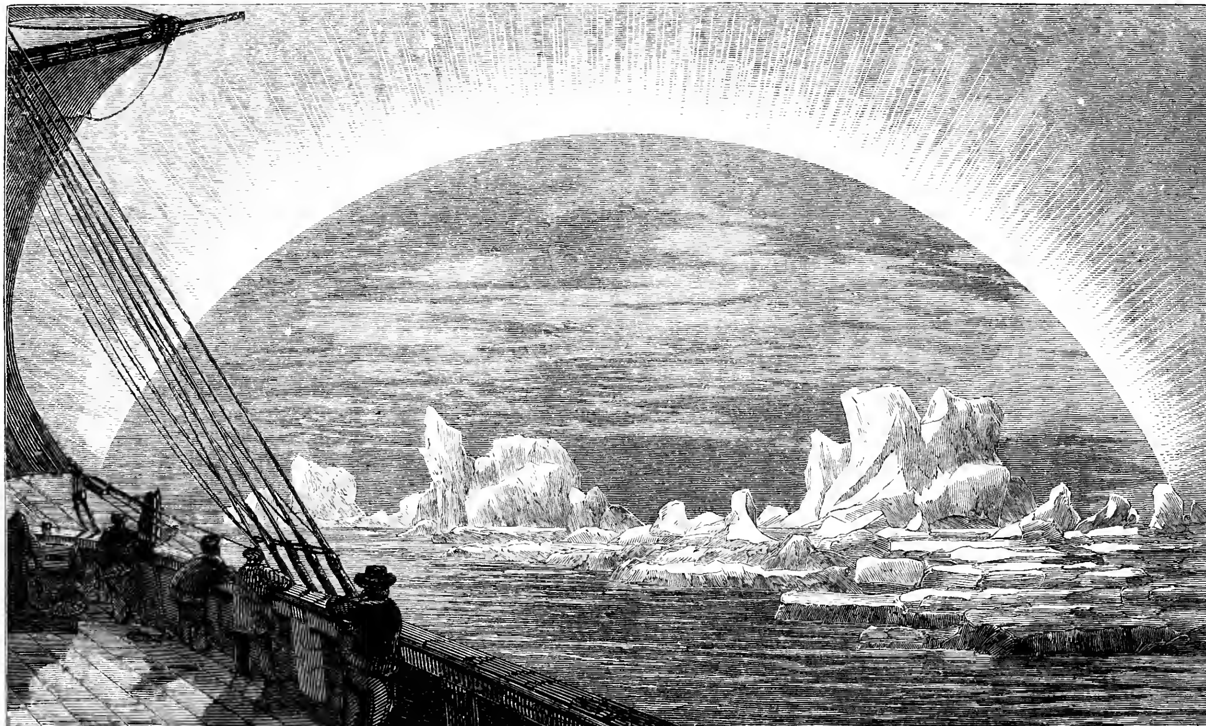

AURORA BOREALIS IN THE ARCTIC SEA.

ELECTRIC SCIENCE;

ITS HISTORY, PHENOMENA, AND APPLICATIONS.

BY

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Illustrated with upwards of One Hundred Wood-Engravings.

LONDON:

INGRAM, COOKE, AND CO.

1853.

LONDON:
PRINTED BY ROBSON, LEVEY, AND FRANKLYN,
Great New Street and Fetter Lane.

PREFACE.

The attention that electricity now commands, by its intimate relations with the other physical sciences and by the important objects to which it is applied, makes it particularly desirable that the student of natural philosophy should have the means of attaining, in a compendious form, a knowledge of the progress of electric science to the present day, and of comprehending its varied phenomena, and the applications of which it has been found capable. With this object in view, the author has endeavoured to set forth clearly, yet concisely, the prominent points in the history of electricity, and to notice and explain all those phenomena which indicate any special attribute of that peculiar force.

In attempting to comprise all that is important to be known of the history, the phenomena, and the applications of electricity within a single volume, there is considerable risk of producing a mere chronological record and an explanatory catalogue rather than an interesting treatise. When, indeed, it is considered that Priestley's *History of Electricity* occupies a thick quarto volume—though written before the most important sources of electric force had been revealed by Galvani and Volta, by Œrsted, Seebeck, Faraday, and Armstrong—it might be supposed that a history which includes those discoveries, and is contained within forty pages, must be only a barren sketch. To afford space for circumstantial illustration and explanatory remarks, attention has been concentrated on the characteristic facts, by the adoption of which course it is hoped that the historical notice of the advancement of electric science will be found interesting as well as instructive.

As a mere statement of effects would have proved unsatisfactory without an explanation of the causes that produce them, such explanations have been given as appeared to the author to afford the clearest insight into the nature of electrical action. Though the Franklinian theory of

the excitement of frictional electricity has been generally adopted, because it is the most simple, and voltaic action has been attributed to chemical agency, theoretical discussions have been avoided as much as possible, lest they might tend to obscure rather than to throw light on the causes of electrical phenomena. In some few instances views have been taken of the action of electric force different from those commonly entertained; but in such cases the reasons for the departure from received opinions have been fully stated.

The author is not aware that the many varied inventions for the application of electric power to the uses of man have been previously described collectively. In noticing them, prominence has been given to those objects that are of the greatest importance; it having been considered sufficient in appliances of less consequence merely to indicate the mode of operation, and to explain the principles of their action.

By dividing the consideration of electric science into its history, phenomena, and applications, some repetitions have almost unavoidably occurred, in order to make each part complete in itself. It is conceived, however, that the advantages attending such an arrangement, by affording a clearer conception of each branch of the subject, more than counterbalance the inconvenience of occasionally going, for a short distance, over the same ground.

HAVERSTOCK TERRACE, HAMPSTEAD,
June 1853.

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ELECTRIC SCIENCE:

ITS HISTORY, PHENOMENA, AND APPLICATIONS.

PART I.

THE HISTORY OF ELECTRICITY.

CHAPTER I.

First discovery of electric attraction—Dr. Gilbert's additions to known electrics—Curious fallacies of early electricians—Invention of the electrical machine—Discovery of electric light and repulsion—Identity of electricity and lightning suggested—Distinction between conducting and non-conducting bodies discovered—The two kinds of electricity discovered by Du Fay—Sparks from the human body—Improvements in electrical machines—Igniting power of the electric spark—The Leyden jar—Extraordinary alarm at the electric shock—Exaggerated descriptions of its effects—Electrical batteries—Dangerous shocks given with them—Conducting power of the earth ascertained—Dr. Franklin's theory of electricity.

There requires no deep research in the pages of antiquity to trace the rise and progress of the science of electricity. It sprang into being in comparatively recent times; and after the first halting-stages of its existence were surmounted, it advanced from infancy to manhood with the rapidity of its own lightning spark; and though not yet arrived at maturity, it has attained a degree of importance scarcely to be equalled by any of the physical sciences.

Some of the ordinary phenomena of electricity, indeed, attracted observation from the earliest periods. Not to mention lightning and its accompanying thunder, the excitement of sparks by the rubbing of furs must have been noticed, and wondered at, by the nomad tribes who first inhabited the earth. The earliest recorded observation of electrical phenomena, however, occurs 600 years before the Christian era. About that time, it is stated that Thales of Miletus, one of the seven sages of Greece, remarked that amber, when rubbed, attracted light bodies to its surface. This seems to have been the extent of his observations; but the fact afforded ample matter for speculation. He conceived that amber must possess some inherent living principle, called into action by friction, and that when thus excited it emitted an invisible effluvium, constantly returning to itself, and bringing back with it those substances which were not too heavy to resist its adhesive force. The next recorded notice of elec-

trical attraction is given by Theophrastus, 300 years afterwards. He remarked that the crystal called by him *lyncurium*, supposed to be tourmalin, attracted light bodies to its surface.

The shock given by the torpedo is mentioned by Pliny; but that phenomenon was not, until the middle of the last century, imagined to have any connection with the attractive properties of amber and tourmalin. Some very remarkable facts are also mentioned by Eustathius, who lived in the fifth century of the Christian era. He states that a freedman of Tiberius was cured of the gout by the shock of the torpedo; the first known instance of the application of electricity to medical purposes, and, if authentic, much more successful than its application in modern times. Eustathius further relates, that Wolimer, king of the Goths, was able to emit sparks from his body; and that a certain philosopher, whilst dressing and undressing, emitted flashes of light.

There is a void of nearly 1200 years ere we find any other distinct notice of electrical phenomena. The subject must, however, have attracted attention; for at the beginning of the seventeenth century a book by Dr. Gilbert was published, entitled *De Magnete*, in which many other substances besides amber and tourmalin are mentioned as having the property of attracting light bodies when rubbed; but as amber was the substance first noticed to possess that property, its Greek term *electron* had precedence in giving a name to the infant science of electricity.

When we consider that previously to the announcement of Dr. Gilbert's discoveries, the only known electrics were amber, tourmalin, and jet, the accessions he made to the number must be regarded as an important first step in the progress of electricity. He added at least twenty to the list of electrics, including most of the precious stones, glass, sulphur, sealing-wax, and resin; and he determined that those substances, when rubbed under favourable circumstances, attract not only light floating bodies, but all solid matters whatever, including metals, water, and oil. He observed also that the conditions most favourable to the excitement of the attractive power are, a dry state of the atmosphere, and a brisk and light friction; whilst moist air and a southerly wind he found to be most prejudicial to the production of electrical effects.

The deductions of Dr. Gilbert from his experiments were in many instances curiously fallacious. In pointing out, for instance, the distinction between magnetic and electric attraction, he affirmed that though magnetic bodies rushed together mutually, it was only the excited electric that exerted any power on the bodies attracted; and he noticed as a special distinction between magnetism and electricity, that the former repelled as well as attracted, whilst the latter only attracted.

After the discoveries and investigations of this father of electric science, there was a lapse of about sixty years with scarcely any progress. Mr. Boyle is the next person whose investigations are worth mention. Though he repeated and confirmed former experiments, and devoted much time to the subject, he did little more than add some few to the number of electrics. This philosopher has, indeed, the reputation of being the first who discerned the electric light; but his notice of it was so indistinct that he can scarcely be said to be the discoverer of the luminous property of electricity.

Mr. Boyle's theory of electrical attraction was similar to that of Thales;

without, however, attempting to assign a cause for the active principle. He conceived that the excited electric emitted a glutinous effluvium which laid hold of small bodies in its progress, and on its return to the electric carried them with it. This theory was advocated by other electricians at the time, and experiments were made, and are recorded in the *Philosophical Transactions,* which were considered to prove the emission of glutinous particles.

The most important advances in the science at this time were made by Otto Guericke, burgomaster of Madgeburgh, the inventor of the air-pump, who was contemporary with Mr. Boyle.

The apparatus with which electricians had experimented till near the end of the seventeenth century was of the most simple kind. A rod or flat surface of glass, resin, or sulphur, rubbed with the hand or with a piece of woollen, was their best means of exciting electricity; it may therefore be supposed that the quantity at any time under observation was very small. Otto Guericke constructed the first electrical machine. It consisted of a sulphur globe, whirled round on an axis, whilst he held his hand to it to serve as a rubber. Sulphur, it may be remarked, was a favourite electric with early experimenters, as it was imagined that electricity was emitted with the sulphurous effluvium produced by the friction. In the construction of M. Otto Guericke's electrical machine, for example, he cast the sulphur in a glass globe, and then broke the glass—which would have served the purpose better—in order to expose the sulphur to the action of the rubber. With this machine, rude as it was, Otto Guericke excited much greater quantities of electricity than had previously been produced; and he was thus enabled not only to see flashes of light, but to hear the snapping noise of the electric spark.

It may seem extraordinary that the most commonly observed phenomenon of electricity had not been before noticed as a property pertaining to electrical bodies. It should be borne in mind, however, that furs and silks, from the friction of which sparks are so frequently emitted, had not been classed as electrics, and the only property of electricity then known was that of attraction. It was not likely, therefore, until the two phenomena of attraction and the emission of light were observed combined in the same substance, that the excitement of sparks by friction should be considered due to electricity.

On Otto Guericke must also be conferred the honour of having discovered the property of electric repulsion. He ascertained that a feather, when attracted to an excited electric, after adhering to it for a short time, is repelled from the surface, and that it will not again approach until it has touched some other body to which it can part with the electricity it contains. He observed, also, that a feather when thus repelled by an excited electric, always keeps the same side presented towards it. As there was a correspondence between this fact and the position of the moon towards the earth, it was assumed that the revolution of the moon round the earth might be caused by electrical attraction and repulsion.

The discoveries of Sir Isaac Newton, shortly afterwards, dispelled this notion, and so far engaged the attention of scientific inquirers, that electricity for a time remained in abeyance. Newton had, indeed, paid a passing attention to electrical phenomena, but the only addition made by him to the facts before collected was, that electric attraction and repulsion

penetrate through glass. He made known, for instance, that when a plate of glass is excited on one side, the other side also becomes electrical.

About the same time that Otto Guericke obtained decisive evidence of the luminous properties of electricity, the fact was made more strikingly manifest by Dr. Wall, who operated with a stick of amber of large dimensions. He used a piece of woollen cloth for a rubber, and appears to have been remarkably successful in eliciting by that means a greater amount of electricity than had been excited even with the sulphur-globe of Otto Guericke.

The first idea of resemblance between electrical phenomena and thunder and lightning was suggested to Dr. Wall by the apparently remote analogy of the crackling sounds and sparks; and the fact deserves to be recorded in his own words: "From the friction of the amber," he observes, "a prodigious number of little cracklings were heard, and every one of these produced a little flash of light. And what to me is very surprising, upon its eruption it strikes the finger very sensibly, wheresoever applied, with a push or a puff like wind. The crackling is full as loud as charcoal on fire; and five or six cracklings or more, according to the quickness of placing the finger, have been produced from one single friction, light always succeeding each of them. *This light and crackling seems in some degree to represent thunder and lightning.*"

Little further progress was made for nearly forty years. During that interval, the accumulation of facts and improvements in the apparatus were slow and insignificant. As yet, experimenters had worked without any system, and without in the least comprehending the principles on which the effects they produced depended. It was not until 1729—nearly 130 years after the first book on the science had been published—that the distinction between conductors and non-conductors of electricity was discovered. This important fact was accidentally ascertained by Mr. Stephen Grey, whilst attempting to communicate electricity to a line suspended by threads. His first experiments were unsuccessful, because he suspended the line by threads that conducted the electricity from it nearly as quickly as it entered. It was then suggested by Mr. Wheeler, who assisted at the experiment, that the cause of the escape of the electricity was the thickness of the packthread employed, and he recommended that silken threads should be tried, because being much thinner, it was supposed the electric fluid would not be able to flow through it so readily. Accordingly the silk thread was tried, and with great success.

So little were the experimenters aware that the difference in the effects was caused by the different conducting properties of the substances employed, and so impressed were they with the notion that success with the silk suspenders was entirely owing to their superior fineness, that they endeavoured to obtain still better results by suspending the line on very fine *wires*. The total failure of the experiment in this case induced them at length to consider that there must be a difference in the conducting properties of the substances employed.

The attention of electricians having been thus directed to this subject, light was gradually, though still feebly, thrown on the causes of success and failure in their experiments under different circumstances. Lists of conducting and of non-conducting substances were made, when it was found that glass, resin, and all bodies known as electrics, were bad conductors of

electricity, and that those in which electricity could not be excited were conductors. In the conducting and non-conducting properties of these substances great difference was soon detected; glass and resin being the worst, and metals the best conductors.

Nearly contemporaneously with the discovery of the different conducting properties of electrics and non-electrics was the announcement that M. Du Fay, intendant of the French king's gardens, had detected the existence of two distinct kinds of electricity. This, like all the other discoveries hitherto made, originated from accidental circumstances. A piece of gold-leaf having been repelled from an excited *glass* rod, M. Du Fay pursued it with an excited rod of *sealing-wax*, expecting that the gold-leaf would be equally repelled by that electric; but he was astonished to see it, on the contrary, attracted to the wax. On repeating the experiment he found the same result invariably to follow: the gold-leaf when repelled from glass was attracted by resin; and when repelled from the latter was attracted by glass. Hence M. Du Fay assumed that the electricity excited by the two substances was of different kinds; and as one was produced from glass, the other from resin, he distinguished them by the names *vitreous* and *resinous* electricity.

It is a curious fact that M. Du Fay, the discoverer of this important property of electricity, afterwards repudiated his own discovery. Subsequent experiments and consideration induced him to depart from the truth he had developed, and to imagine that the effects observed arose entirely from difference in the degrees of force excited by different electrics; the more powerful attraction of the one overcoming the feeble repulsion of the other. It is difficult to conceive how he could have thus retrograded from the position he had established; for supposing the gold-leaf when repelled from the excited glass to have been attracted to the resin by superior electrical force, this superiority of force could not have yielded to the weaker attraction of the glass; yet the mutual interchange of attractive and repellent power must have been frequently noticed. Other investigators, however, confirmed the fact he had discovered and thus singularly renounced; and the original terms "vitreous" and "resinous" electricity continue to be retained by a majority of electricians.

One of the experiments devised about this period, which excited great astonishment, and tended to direct the attention of philosophic inquirers to the subject of electricity, was the development of sparks from the human body. Mr. Grey suspended a boy horizontally with hair lines, and communicated electricity to him by means of an excited glass tube, when sparks were then drawn from all parts of the boy's body. This phenomenon, depending simply on the fact that the bodies of animals are conductors of electricity in consequence of the fluids they contain, was conceived to be owing, in some mysterious manner, to a connexion between the electric effluvium, as it was called, and the vital principle. M. Du Fay suspended himself in a similar manner for the purpose of experiencing the sensation, and the experiment soon afterwards became the most popular in the range of electrical phenomena, when the more convenient mode of insulation by standing on a cake of resin, or on a glass stool, was introduced.

About the middle of the 18th century, the investigation of electrical phenomena was undertaken by several scientific inquirers in Germany.

M. Boze, Professor of Philosophy at Wittemburg, made considerable improvement in the mode of exciting electricity, by the addition of metal conductors to the revolving glass globes of his machines. In the first instance his conductor was held by a man, insulated by standing on a cake of resin; but he shortly afterwards adopted the more convenient method of supporting the conductor by means of silk cords; and to facilitate the passage of the electricity from the excited globe, he added a number of linen strings to the conductor, which served the purpose, though very imperfectly, of the metal points subsequently used. M. Boze and other experimenters adopted the plan of increasing the quantity of electricity excited, by bringing several globes into action at the same time, and concentrating their power in one conductor. With these instruments they are represented to have produced effects which seem incredible with such imperfect apparatus, and the accounts must be considered to be greatly exaggerated. It is stated, for instance, that by sparks from these electrical machines blood was drawn from the finger; that they produced a sensible shock extending from the head to the feet; and that they were sufficiently powerful to kill small birds. Even with the improved electrical apparatus of the present day, with the addition of metal points and amalgamated rubbers, at that time unknown, nothing approaching these effects can be produced by the largest machines.

Of the experiments performed by the continental philosophers at this period, none excited so much general interest as the setting on fire of inflammable substances. This was first accomplished by Dr. Ludolph, of Berlin; and the experiment was quickly repeated and improved on in different parts of Europe. The inflammation of spirits of wine, of phosphorus, and even of gunpowder, by an electric spark emitted from the finger of a person insulated by standing on resin, was considered so extraordinary, that it not only drew the attention of more men of science to this branch of natural philosophy, but the exhibition of these and other electrical wonders became a very popular public entertainment.

Quickly following the development of the igniting powers of the electric spark was the discovery of the Leyden phial, the most astonishing of any of electrical phenomena then made known, and which opened an entirely new field for scientific investigation.

For the honour of being the original discoverer of the Leyden phial there were several claimants; as is generally the case with important discoveries and inventions. It is commonly attributed to M. Cuneus of Leyden, at the beginning of the year 1746, and was, like all antecedent discoveries, the effect of accident, so far, at least, as he was concerned. It occurred to him whilst repeating a well-devised experiment of Professor Muschenbrœck for collecting and confining the "electric effluvium." The professor conceived, if he could impart electricity to a conducting substance entirely surrounded by non-conductors, that it would be thereby prevented from being dissipated, and the force might be concentrated. The most convenient form of trying the experiment appeared to be to electrify water contained in a glass bottle, connection with the conductor of the machine being established by an iron nail passing through the cork into the water. The experiment, however, was not attended with any results to Professor Muschenbrœck. The object he contemplated was, indeed, accomplished, but the accumulation of electricity in the phial was not

manifested, owing to the want of a conducting surface on the outside by which it could be concentrated. M. Cuneus, in repeating the experiment, happened to grasp the bottle with his hand, which thus served for the requisite conducting surface outside the glass, and when with the other hand he endeavoured to disengage the nail from the conductor of the machine, he was startled by receiving a smart shock through his arms. Professor Muschenbrœck then renewed the experiment, with the advantage of the experience of M. Cuneus, and with equal success. In these experiments with the Leyden phial, and for a considerable time afterwards, the bottle was always grasped by the hand, the cause of its producing the effect not being understood.

Though M. Cuneus acquired the reputation of being the discoverer of the Leyden phial, the claim of M. Von Kleist, dean of the Cathedral of Camin, to be the first discoverer, rests on strong ground. It is stated that he sent an account of the discovery to Dr. Leiberkuhn of Berlin, on the 4th November, 1745. This account, commuuicated to the Academy of Berlin, and entered among their proceedings, is to the following effect: "When a nail or a piece of thick brass wire is put into a small apothecary's phial and electrified, remarkable effects follow; but the phial must be very dry or warm. I commonly rub it over beforehand with a finger on which I put some pounded chalk. If a little mercury, or a few drops of spirit of wine be put into it, the experiment succeeds the better. As soon as this phial and nail are removed from the electrifying glass, or the prime conductor to which it has been exposed is taken away, it throws out a pencil of flame so strong, that with this burning instrument in my hand I have taken above sixty steps in walking about my room. When it is electrified strongly, I can take it into another room, and there fire spirits of wine with it. If, whilst it is electrifying, I put my finger, or a piece of gold which I hold in my hand, to the nail, I receive a shock which stuns my arms and shoulders. A tin tube, or a man, placed upon electrics, is electrified much more strongly by this means than in the common way. When I present this phial and nail to a tin tube which I have, fifteen feet long, nothing but experience can make a person believe how strongly it is electrified. Two thin glasses have been broken by the shock. It appears to me very extraordinary that when this phial and nail are in contact with either conducting or non-conducting matter, the strong shock does not follow. I have cemented it to wood, glass, sealing-wax, metal, &c., which I have electrified without any great effect. The human body, therefore, must contribute something to it. This opinion is confirmed by observing that unless I hold the phial in my hand, I cannot fire spirits of wine with it."

The foregoing account of M. Von Kleist's experiments clearly shews that he had stumbled on the same discovery as M. Cuneus; and the date is previous to the experiment of the latter. It appears, however, that the dean was not aware of the full importance of grasping the bottle during the experiment, and his description was so vague, that several philosophers to whom he communicated the discovery were unsuccessful in their attempts to repeat the experiments.

The physiological effects of the Leyden phial were those that naturally excited most attention in the first instance; and the accounts given by some of the early experimenters of the sensation of the electric shock

exhibit curious illustrations of the exaggeration caused by the terror of this novel agitation of the nervous system. The small and inefficient apparatus experimented with could have produced only very feeble shocks, yet the effects are represented to have been little less than those of a flash of lightning. These exaggerations are the more remarkable, when it is borne in mind that they proceeded from eminent philosophers accustomed calmly to investigate physical phenomena. M. Muschenbrœck, for example, says in a letter to M. Reaumur, that he felt himself struck in his arms, shoulders, and breast, so that he lost his breath, and was two days before he recovered from the effects of the blow and the terror. He adds, that he "would not take another shock for the whole kingdom of France."

M. Allamand, a fellow-professor with M. Muschenbrœck, and who assisted in the experiments which led to the discovery, stated that he lost his breath for some moments after taking the first shock; and that he felt so intense a pain along his right arm, that he apprehended serious consequences from it. Another distinguished electrician, Professor Winckler of Leipsic, said that the first time he tried the experiment his body was greatly convulsed, and that it put his blood into such violent agitation that he was apprehensive of an ardent fever, and was obliged to take refrigerating medicines. He also felt great heaviness in his head, as if a stone were laid upon it. On two other occasions he said the shock made his nose bleed, to which he had not been previously disposed.

The astonishing effects of the electric shock were calculated to draw public attention to the subject of electricity more than any previous discovery. Every one was anxious to see the effects and to experience the new sensation, notwithstanding the terrible accounts given of it. Travelling showmen with their Leyden phials and electrical machines were to be seen in all parts of Europe, who found profitable employment in exhibiting that and other striking electrical phenomena. Nor were philosophers idle in the new field of inquiry which this discovery opened to their investigation. The properties of the Leyden phial were closely examined; the conditions requisite to the development of the phenomena were better understood; and many ingenious, though fallacious, theories were devised for their explanation. The construction of the apparatus was improved by the addition of an outside metallic coating, and jars were substituted for bottles, by which means a metallic lining could be applied also to the inside of the glass.

Many interesting experiments exemplified still more strongly the powerful and rapid action of electricity. The shock was communicated at the same instant through one hundred and eighty of the French guards, in the presence of the King of France, by joining their hands in a connected chain; the soldier at one end touching the outside of the jar, and the man at the other end touching the wire connected with the inside coating.

By combining several jars together to form an electrical battery, the force was greatly accumulated; so as to set fire to all kinds of inflammable substances, to melt fine wires and gold and silver leaf, and to kill small animals.

Though the feeble shocks of the small phials employed in the early stages of the discovery created such a state of nervous apprehension, and produced, as we are told, such distressing effects, yet within a

few years of that period we find electricians receiving shocks of really formidable power with remarkable stoicism, and giving similar charges to others, in a manner that would now be considered highly dangerous. Dr. Franklin, the American philosopher, for instance, experimented with glass jars containing six gallons each; and whilst trying the destructive power of the electric shock on some fowls, he inadvertently received the full charge of two of these very large jars through his arms and body. The effects, as he describes, were "sufficiently severe;" yet the daring philosopher merely mentions them as shewing that a man can bear without much detriment a shock greater than he had imagined. He said that on receiving the shock, it seemed like a universal blow through the body from head to foot, and was followed by a violent quick trembling in the trunk, which went off gradually in a few seconds. It was some minutes before he could collect his thoughts so as to know what was the matter; for he did not see the flash, though his eye was on the spot of the prime-conductor, from whence it struck the back of his hand; nor did he hear the crack, though the bystanders said it was a loud one; nor did he particularly feel the stroke on his hand, though it raised a small swelling there. His arms and the back of his neck felt somewhat numbed the remainder of the evening, and his breast was sore for a week after, as if it had been bruised.

Electricians of the present day would not venture to repeat such an experiment as the following, of which an account is given by Franklin in a letter dated Philadelphia, 1755. "The knocking down of six men was performed with two of my large jars, not fully charged. I laid one end of my discharging-rod upon the head of the first; he laid his hand on the head of the second; the second his hand on the head of the third, and so to the last, who held in his hand the chain that was connected with the outside of the jars. When they were thus placed, I applied the other end of my rod to the prime conductor, and they all dropped together. When they got up, they all declared they had not felt any stroke, and wondered how they came to fall; nor did any of them either hear the crack or see the light of it. You suppose it a dangerous experiment; but I had once suffered the same myself, receiving by accident an equal stroke through my head that struck me down without hurting me; and I had seen a young woman that was about to be electrified through the feet (for some indisposition) receive a greater charge through the head by inadvertently stooping forward to look at the placing of her feet, till her forehead (as she was very tall) came too near my prime conductor: she dropped, but instantly got up again, complaining of nothing. A person so struck sinks down doubled, or folded together as it were, the joints losing their strength and stiffness at once, so that he drops on the spot where he stood instantly, and there is no previous staggering, nor does he ever fall lengthwise. Too great a charge might, indeed, kill a man, but I have not yet seen any one hurt by it. It would certainly, as you observe, be the easiest of all deaths."

With the powerful batteries employed by Franklin he also succeeded in communicating magnetism to steel needles. This had, indeed, been previously done by others, but not in so satisfactory a manner.

Numerous experiments were undertaken by Dr. Watson, Lord C. Cavendish, and other gentlemen associated with them, for the purpose of

ascertaining the rapidity of the electric discharge, and the distances it could be transmitted through water and dry ground. In one of these experiments, performed in 1747, an electric discharge was sent across the Thames; and in another, near Shooter's Hill, the discharge passed instantaneously through two miles of wire and two miles of dry ground without any perceptible interruption.

These experiments deserve special notice at the present day, as they established the fact of the conducting property of the earth, which has been turned to such good account in the construction of electric telegraphs. Another fact also intimately bearing on the same subject was ascertained by Signor Beccaria, viz. that water is an imperfect or a good conductor of electricity in proportion to its quantity. This conclusion was drawn from experiments in sending electric discharges through tubes of different sizes filled with water; when it was found that a charge which passed freely through the larger was obstructed by the smaller tubes.

Numerous speculations were broached to account for the phenomena of the Leyden phial, but the nature of its action was very imperfectly understood until Dr. Franklin undertook the investigation. It had, indeed, been discovered that a jar could not be charged whilst it was insulated from the earth; but this circumstance, which afforded a clue to the elucidation of the phenomena of the Leyden phial, remained a barren fact until it attracted Franklin's observation. He was the first to discover that the electricity on the outside of the jar is of a different kind from that within; and that in charging a jar, a quantity of electricity is expelled from one side of the glass equal to that introduced on the other. Hence the necessity of supplying a passage to the electricity outside by connecting it with a conducting substance, which had hitherto remained unaccounted for. According to Franklin's view of the condition of a charged Leyden phial, the inside when charged from excited glass is filled with what had been termed vitreous electricity, and the outside is equally charged with electricity of the opposite kind. These electricities having a strong mutual attraction, and being kept asunder only by the resistance offered by the non-conducting glass and surrounding air, instantly rush together when the opposite surfaces are brought in connexion, producing all the phenomena of the Leyden phial, and leaving the glass in its original neutral condition.

Franklin also proved more satisfactorily than had previously been done, that the electric charge is in the glass, and not in the metallic coatings of the jar, which serve merely to conduct, and to concentrate to one point, the electricity spread over the surface of the glass. To illustrate this fact most conclusively, he contrived a jar with loose metallic coatings, that could be removed and changed for others after the jar was charged; and this change being effected, the amount of electricity was found to be scarcely diminished.

The simple and beautiful theory of Franklin for explaining the action of the Leyden jar is one of the most important contributions of that philosopher to the science of electricity. Amplifying and improving the views that had previously been taken by Dr. Watson, he conceived that the friction of glass and of other electrics does not generate electricity, but that it causes a disturbance of the quantity of the electric fluid preexisting; producing thereby in some bodies an excess and in others a

deficiency. The terms *positive* and *negative* were introduced to designate these states of repletion and want; and these terms have been generally adopted in this country in speaking of the two kinds of electricity. It will be observed, therefore, that it formed an essential part of this theory to consider the phenomena of electricity as produced entirely by the disturbance of the equilibrium of the same ethereal fluid, the particles of which were mutually repulsive. On this principle was explained the effect of bodies similarly electrified repelling each other, and the attraction of the opposite electricities was attributed to the force exerted in attempting to restore the equilibrium.

The application of this theory to explain the action of the Leyden jar presents a perfectly satisfactory view of the phenomena. When, for example, the wire connected with the interior coating is brought near the conductor of an electrical machine, an effort is made to part with a portion of its excess of the electric fluid to the jar; but the latter cannot receive an addition to its natural quantity inside until an equal quantity of that on the outside is expelled by means of some conducting body connected with the earth. The inside thus becomes positively electrified and the outside negatively, and in equal degrees. The resistance offered to the passage of the electric fluid by the uncovered portion of the glass and by the surrounding air, prevents the two electricities from coalescing until the metallic surfaces of the jar are brought sufficiently near, by means of connecting conductors, to enable the attractive powers of the opposite electricities to overcome the interposed resistance.

The Franklinian theory of electricity is not without difficulties, especially in the explanation of repulsion from bodies electrified negatively; and the philosophers on the continent have adopted the vitreous and resinous theory of Du Fay. But the great simplicity of Franklin's hypothesis, and its accordance with those theories which have been established as affording the most satisfactory explanation of phenomena in other departments of science nearly related to electricity, have enabled it to maintain its ground in this country; and from the time of the announcement of Franklin's theory much clearer notions of the principles of electrical action were generally entertained.

CHAPTER II.

The identity of lightning and electricity pointed out by Franklin—Electricity drawn from the clouds in France—Franklin's electrical kite—Lightning-conductors invented—Dangerous experiments with lightning—Death of Professor Richmann—Beccaria's experiments on atmospheric electricity—Electrical induction discovered—The theory of vitreous and resinous electricity revived—Measurement of electric forces—Inventions of the torsion balance and of the electrophorus—Progress of discovery to the end of the eighteenth century.

We now approach another important epoch in the history of electricity, in which Dr. Franklin's powers of philosophical research and his fertility of invention are eminently conspicuous.

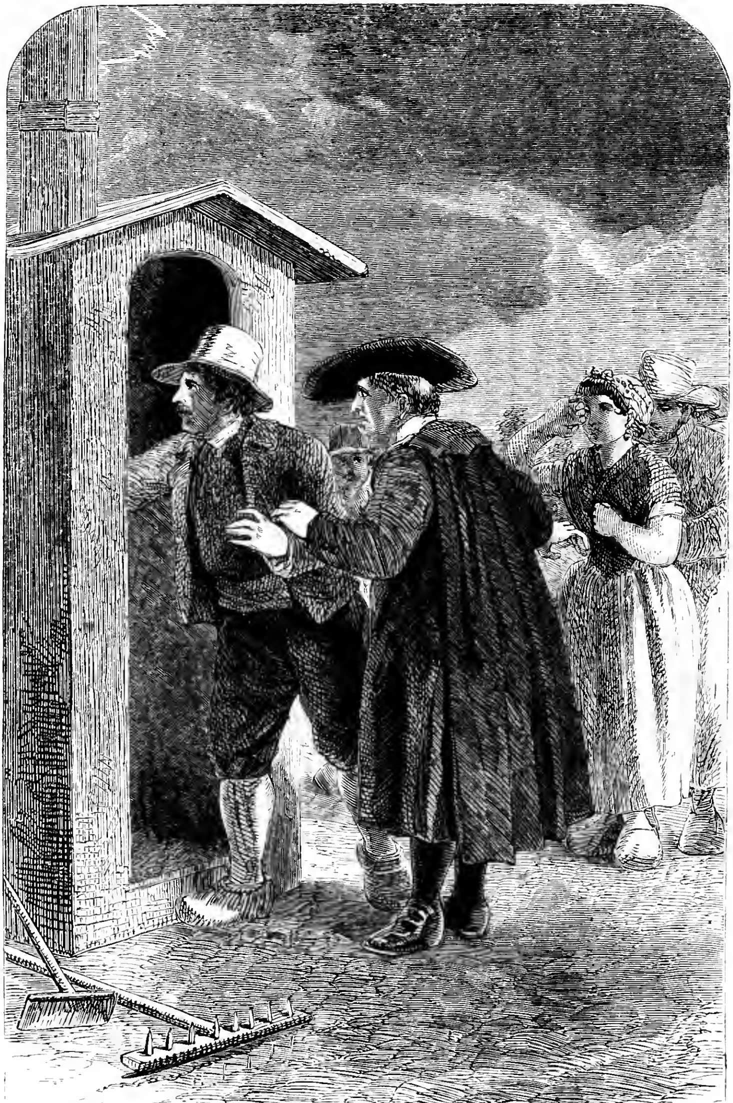
The flashing light, and the snapping noise of the electric spark, had

induced some of the earliest electricians to imagine a similarity between those manifestations of electricity and the phenomena of thunder and lightning. We have previously quoted the remarkable words of Dr. Wall, alluding to this probable identity, at a time when the known facts were so few as to have made the analogy seem merely fanciful. The further development of electrical force, especially after the discovery of the Leyden phial, enabled experimenters to imitate on a small scale many of the destructive effects of lightning.

The observations of the Abbé Nollet bear so close a relation to the truth, that they deserve to be recorded, as indications how well prepared philosophers at that time were for the subsequent discovery of Franklin. In his *Leçons de Physique* the Abbé says: "If any one should take upon him to prove from a well-connected comparison of phenomena, that thunder is in the hands of nature what electricity is in ours, that the wonders which we now exhibit at our pleasure are minor imitations of those great effects which frighten us, and that the whole depends upon the same mechanism; if it is to be demonstrated that a cloud prepared by the action of the winds, by heat, by a mixture of exhalations, &c., is opposite to a terrestrial object; that this is the electrified body, and at a certain proximity from that which is not,—I avow that this idea, if it was well supported, would give me a great deal of pleasure; and in support of it how many specious reasons present themselves to a man who is well acquainted with electricity! The universality of the electric matter, the readiness of its action, its inflammability, and its activity in giving fire to other bodies, its property of striking bodies externally and internally even to their smallest parts, the remarkable example we have of this effect in the experiment of Leyden, the idea which we might truly adopt in supposing a greater degree of electric power, &c.; all these points of analogy which I have been sometime meditating, begin to make me believe that one might, by taking electricity for the model, form to one's self in relation to thunder and lightning more perfect and more probable ideas than have been hitherto offered."

No one, however, had devised a means of ascertaining the identity of lightning and electricity until Franklin pointed out the way of drawing electricity from the clouds; nor would he probably have thought of the means of doing so but for the results of an unsuccessful experiment undertaken by his friend Mr. Hopkinson. That gentleman electrified an iron ball with a needle fixed to it, expecting to draw a stronger spark from the point, as from a kind of focus; but he was greatly surprised to find that, instead of increasing the intensity of the electricity, the point dissipated it altogether. He mentioned the failure of the experiment to Dr. Franklin, who immediately undertook to investigate the cause, and to determine the influence of points in attracting electricity. In repeating the experiment, he ascertained not only that the ball could not be electrified when a needle was fastened to it, but that when the needle was removed and the ball was charged with electricity, the charge was silently and speedily withdrawn when a point connected with the earth was presented to it.

From this effect of points on electrified bodies, Franklin inferred that lightning might also be drawn silently and safely from the clouds by a metallic point fixed at a great elevation, and he awaited with considerable anxiety the completion of a spire at Philadelphia to enable him to try the



p. 21.

LIGHTNING FIRST DRAWN FROM THE CLOUDS.

experiment. In the meantime he published the results of his discoveries, and recommended that where opportunities occurred the trial should be made.

In a letter to Dr. Lining of Charlestown, containing answers to several questions, Dr. Franklin has given the following account of the origin of the idea that led to the grand discovery. "Your question, how I came first to think of proposing the experiment of drawing down the lightning in order to ascertain its sameness with the electric fluid, I cannot better answer than by giving you an extract from the minutes I used to keep of the experiments I made, with memorandums of such as I purposed to make, the reasons for making them, and the observations that arose upon them, from which minutes my letters were afterwards drawn. By this extract you will see that the thought was not so much an 'out-of-the-way one,' but that it might have occurred to an electrician. 'Nov. 7, 1749. Electric fluid agrees with lightning in these particulars: 1. giving light; 2. colour of the light; 3. crooked direction; 4. swift motion; 5. being conducted by metals; 6. crack or noise in exploding; 7. subsisting in water or ice; 8. rending bodies it passes through; 9. destroying animals; 10. melting metals; 11. firing inflammable substances; 12. sulphureous smell. The electric fluid is attracted by points. We do not know whether this property is in lightning, but since they agree in all the particulars in which we can already compare them, is it not probable they agree likewise in this? Let the experiment be made.'"

Acting on this suggestion, M. Dalibard and M. Delor erected apparatus for the purpose of collecting electricity from the clouds; the former at Marly la Ville, about six leagues from Paris, the latter at his residence situated on high ground in Paris itself. M. Dalibard's apparatus consisted of an iron pointed rod forty feet long, the lower end of which was inserted in a sentry-box protected from rain, and on the outside it was fastened to three wooden posts by silk cords also defended from the rain. It was this rod that first attracted electricity from the clouds at a time when, unfortunately, M. Dalibard was not present to witness the realisation of his hopes. He was absent from Marly at the time, and had left the apparatus in charge of a joiner named Coiffier. On the 10th of May, 1752, between two and three o'clock in the afternoon, a sudden clap of thunder made Coiffier hurry to his post, and, according to the instructions given him, he presented a phial furnished with a brass wire to the rod, and immediately saw a bright spark accompanied by a loud snapping noise. After having taken another spark stronger than the first, he called in the neighbours, and sent for the Curé. The latter ran to the spot with all speed, and his parishioners seeing him running, followed at his heels, expecting that Coiffier had been killed by lightning; nor were they prevented from hastening to the spot, notwithstanding a violent hail-storm. The Curé was equally successful in drawing sparks from the iron rod, and instantly despatched an account of the important event to M. Dalibard. The Curé stated that the sparks were of a blue colour, an inch and a half long, and smelt strongly of sulphur. He drew sparks at least six times in about four minutes, and in the course of these experiments he received a shock in the arm extending above the elbow, which he said left a mark such as might have been made by a blow with the wire on the naked skin.

Eight days after the identity of lightning and electricity had been

proved at Marly, the rod erected by M. Delor, which was ninety-nine feet high, yielded electric sparks; and the same phenomenon was afterwards exhibited to the French king and to numbers of the nobility.

In the meantime, Dr. Franklin remained at Philadelphia unconscious of the success which had attended the adoption in France of his suggestion for drawing lightning from the clouds. Becoming impatient to verify his opinion of the identity of lightning and electricity, it occurred to him that he might establish an electrical connection between a thunder-cloud and the earth by means of a boy's kite, without waiting for the completion of the spire. Accordingly, on the first promising occasion, which occurred in June 1752, a month after the success at Marly, he undertook the experiment. Afraid of being laughed at should the expedient fail, he took his son with him to make it appear that he was merely going for the boy's gratification, to assist in flying the kite. The apparatus consisted of a silk handkerchief attached at the corners to two laths placed crosswise. The kite thus constructed was able to bear a shower of rain without being injured, and a pointed wire was fixed to it for the attraction of electricity, but there was not any conducting substance in the string, which consisted of common packthread.

Having raised the kite in the air, he looked anxiously for the result, as some thunder-clouds passed over it, but for some time without any sign of electricity. At length, as he was about despairing of success, he perceived some fibres of the hempen string to stand erect and to avoid one another, just as they would have done if electrified. He then presented his knuckle to a key attached to the string, and to his unutterable delight received a spark. Other sparks succeeded, even whilst the string was dry, and consequently a very imperfect conductor; and when the rain had wetted the string, he drew forth sparks very copiously, with which he charged a Leyden jar. It must be observed that the key was insulated by a silk string to prevent the electricity from passing through the packthread to the earth.

Dr. Franklin afterwards erected an iron rod on the top of his own residence, having found the influence of points to extend farther than he had at first imagined, and one end of the rod being conveyed into his study, he was able at his convenience to perform with lightning all the experiments of artificially-excited electricity. That his attention might be drawn to the apparatus whenever lightning was attracted, he attached a set of bells to the rod, which by the attraction of their clappers gave the signal. Sometimes these bells rang so violently as to be heard all over the house.

The application made by Franklin of his great discovery to the protection of buildings from lightning, was the first practical benefit derived from the science of electricity. He inferred, as points are so efficacious in attracting lightning, that a pointed metallic rod attached to the side of a house, rising some height above it and descending to the earth, would draw off the electricity of a passing thunder-cloud silently, and thus prevent a sudden discharge; or if a flash of lightning should strike the rod, that the electric fluid would be conducted safely through the metal to the ground. He consequently recommended the attachment of such protecting rods to all exposed buildings, and to the masts of ships. Experience has proved the correctness of his inference, and the value of the suggestion. The

plan has been extensively adopted, and has been the means of protecting every building and ship to which such conductors have been properly applied.

Electricians in all parts of the world were anxious to repeat the experiment of drawing electricity from the clouds, and many of them received injuries and had narrow escapes from being killed, in consequence of the hazardous manner in which they performed their experiments. No one succeeded in drawing down such large continuous torrents of electric fire as M. de Romas of Nerac, who employed an electrical kite, in the string of which a thin wire was inserted to serve as a better conductor than the hempen string alone. The kite he used was seven feet high and three feet wide, and a tin tube connected with the wire-string was sustained at a short distance from the ground by means of a silk ribbon, which served, when the kite was elevated, to insulate the wire from the operator. In experimenting with this kite, when raised to a height of 600 feet, in August 1756, the streams of fire issuing from the tin tube were one inch thick, and ten feet long; and on one occasion a loud explosion was heard and a flash of lightning passed from the tin tube to the earth, making a small hole in the ground. At such times, when the flow of electricity was very abundant, M. de Romas experienced the same sensation over his face as is produced when near the prime conductor of an excited electrical machine, which induced him to retreat and discontinue the experiments, from the dread of receiving a shock. Experience had taught him caution; for when he first raised his kite, and whilst taking hold of the wire-string, he was struck severely. M. Mormier, a member of the Academy of Sciences, and M. Bertier of Montmorency, were both knocked down by flashes of lightning, whilst taking sparks from their apparatus; and numerous other persons were more or less injured.

A fatal warning of the danger of experiments with lightning was given by the death of Professor Richmann of St. Petersburgh, on the 26th of August 1753. He had constructed an instrument which he called an *electrical gnomon*, to measure the strength of electricity, and was observing the effect of a thunder-cloud on this instrument, accompanied by M. Solokow, an engraver. Professor Richmann was standing with his head inclined towards the gnomon, when M. Solokow, who was close to him, observed, as he expressed it, "a globe of blue fire as large as his fist," dart from the rod of the gnomon towards the Professor's head, which was about a foot distant. This flash caused the instantaneous death of the Professor, and M. Solokow was so much stunned that he could give no particular account of the effects upon himself. He said that there arose a sort of steam or vapour which entirely benumbed him, and made him sink down upon the ground, so that he could not even hear the accompanying clap of thunder, which was very loud. The effects of the lightning were very apparent in the room; the door-case was split through, and the door torn off its hinges and thrown down.

On examining Professor Richmann's body, a red spot was observed on the forehead, from which some drops of blood issued through the pores, though the skin was not broken. The shoe of the left foot was burst open, and a blue mark was found on that part of the foot; from which appearances it was assumed that the lightning entered the head and passed through the body to the foot. The body itself exhibited several red and

blue spots. With the exception of the left shoe, the dress was uninjured. When the body was opened, twenty-four hours after death, the cranium was without injury, and the brain perfectly sound; but the transparent pellicles of the windpipe were excessively tender, gave way, and were easily rent. There was some extravasated blood in the cavities below the lungs; and the throat, the glands, and the thin entrails were all inflamed. The body so rapidly decomposed, that two days after death it could with difficulty be got into the coffin.

The physiological effect of lightning is exactly the same as that of a shock from a Leyden jar or electrical battery. The author of this work is able to speak from personal experience on this matter, though the shock received by him was too slight to produce any disagreeable consequences. During a severe thunder-storm, accompanied by torrents of rain, he was endeavouring to prevent the overflow of a cistern by stopping up the conduit-pipe, when an electric shock passed through the right arm, from the wrist that was pressing against the pipe to the elbow that rested on the cistern. The effect was very startling, and induced him to make a quick retreat. A loud clap of thunder immediately followed, indicating that a powerful flash of lightning had struck the house; but several metal pipes conducted it safely to the ground, and it was so divided by passing through those conductors that but a very small portion of the discharge could have passed through the imperfect connexion formed by the author's arm.

One of the first objects of scientific experiments on lightning was to determine whether the electricity from the clouds was positive or negative. Franklin found, during all his experiments in the spring of 1753, that the lightning-rod exhibited in every case signs of negative electricity; he therefore concluded, somewhat too hastily, that the clouds are always negatively electrified, and that during thunder-storms it is the earth that strikes into the clouds, and not the clouds into the earth. In a subsequent experiment, however, he found the electricity positive. The observations of other electricians serve to shew that the electrical condition of the clouds frequently varies from negative to positive, and that these changes sometimes occur during the course of the same storm.

The pointed rod with the accompanying apparatus to detect when a thunder-cloud was passing, were soon found to indicate the presence of electricity, not only when there was no thunder-storm, but when the atmosphere was perfectly clear. Signor Beccaria, especially, made searching investigations into the subject, and determined the close connection between electricity and all meteorological phenomena; nor has much been done in elucidating this mysterious connection since the researches of that distinguished philosopher.

The discovery of the identity of lightning and electricity may be considered as the culminating-point in the history of electricity during the last century. No very striking discoveries resulted from the researches of the many electricians who were engaged in investigating the new field opened to their researches; nevertheless numerous interesting facts were made known, and considerable light was thrown on the laws that govern the actions of the electric fluid.

The discovery by Mr. Canton of the property of electrical induction, though not of a character to produce any marked impression at the time, has proved of the utmost consequence in explaining the phenomena of

electricity. In the earlier years of the science an obscure notion was entertained of the influence of excited electrics in bodies at a distance from them; but nothing was actually known of this influence until Mr. Canton proved, by numerous experiments, that an excited electric always induces in other bodies within the sphere of its influence an electrical condition of a kind different from that itself possesses. Mr. Canton found that when he brought an insulated conducting body near to an excited electric, it became electrified so long as it remained there, and that if the electric were positive, that part of the conducting body nearest to it would be negatively electrical, and the more distant part positively. This sympathetic state of electricity, he ascertained, continued only whilst in the vicinity of the excited electric, and that on removing the insulated conducting body, it returned to its natural state. If, however, whilst under the electrical influence, the part farthest from the electric was touched by a conductor, so as to enable it to throw off the electricity repelled to that end, the body remained in an electrical state after the excited electric was removed. These remarkable phenomena were ascribed by Mr. Canton, and also by Dr. Franklin, who verified the experiments, to the presence of electrical atmospheres round all bodies, which atmospheres were supposed to be mutually repellent.

M. Æpinus and Mr. Wilcke, who experimented together with a view to elucidate the cause of the inductive property of electricity, were led to infer that the repelling property exerted at a distance by excited electrics would enable them to charge a space of air included between two conducting plates, in the same manner as a plate of glass is charged when coated on both sides with tin-foil. The experiment answered their expectations, and succeeded at a distance of several inches between two insulated metal discs supported horizontally. When a discharging-rod was connected with the upper and lower plates, a loud discharge, like that of a Leyden jar, instantly took place.

It may be observed that the property of induction might have been deduced from the action of the Leyden jar, as explained by Franklin; but until the experiments of Mr. Canton it could not have been inferred that the presence of positive electricity, which on one side of a plate of glass induces a negative state on the other, would also operate at a distance in communicating negative electricity through the non-conducting air.

Mr. Canton also advanced the progress of electrical science by ascertaining that the kind of electricity excited by the friction of any given substance may be changed from positive to negative, or the reverse, by using different rubbers, or by altering the surfaces of the electrics. Glass is less susceptible of these changes than other electrics, but its generally positive state may be converted into negative by employing the back of a cat for the rubber, or by roughening the surface. To Mr. Canton is also due the merit of introducing the application of a metallic amalgam to the rubber, to increase the facility of exciting electricity.

The opinion which had hitherto been generally entertained, that electrical phenomena depended on the presence of one electric fluid, the equilibrium of which was disturbed by friction, was very ably disputed by Mr. Symmers in a communication to the Royal Society in the year 1759. He adduced several experiments which he considered could only be properly explained on the supposition of the existence of two electric fluids,

not indeed independent, but, on the contrary, always co-existent and counteracting each other. This theory closely resembled that of Du Fay, and his terms of vitreous and resinous electricity were adopted by Mr. Symmers, though Du Fay conceived, in opposition to all observed electrical facts, that the two electricities were independent of each other, and were never combined.

The revival of the theory of vitreous and resinous electricity by Mr. Symmers deserves to be noticed in a history of the science, from the circumstance that, though it did not receive much attention at the time, it has been the foundation of the opinion now generally entertained by electricians on the continent, where the theory of two distinct electric fluids has in a great measure supplanted the more simple *plus* and *minus* theory of Franklin. A very impartial review of the experiments of Mr. Symmers, and of the inferences founded on them, is given by Dr. Priestley,* who, though an advocate of the Franklinian theory, admitted that all the phenomena of electricity might be equally well explained by the supposition of the existence of two distinct fluids as of only one, and that as regards repulsion, the explanation was even more satisfactory. Dr. Priestley, however, adhered to the single fluid as the more simple theory, and as presenting closer analogy to what is known of the operations of nature.

M. Æpinus and the Hon. Henry Cavendish brought mathematical science to bear on the phenomena of electricity, and determined some of the laws that govern its attractive and repellent forces. These researches were pursued still more successfully by M. Coulomb in 1785 with the aid of the electrometer he invented, called the torsion-balance, for measuring the force of electrical attraction and repulsion. In that instrument a filament of silk or spun glass serves to suspend horizontally a fine needle of shellac, with a small gilt pith ball fixed at one end. When the ball is repelled by the excited electric whose force is to be determined, the suspending filament receives a twist from the mutual repulsion of the pith ball and the ball of the electrified conducting body. The two balls thus mutually repelled are forced together by means of a screw to which the filament of glass is attached, and the degree of torsion or twist produced in the filament by forcing the two balls together is measured by an index. The delicacy of the instrument is so great that a force not exceeding the 20,000,000th part of a grain may be indicated. With this sensitive indicator of electrical forces, Coulomb deduced the following important laws as governing the electric fluid :—that bodies electrified by similar electricities repel each other with a force that diminishes in the same proportion as the square of the distance between them is increased ; and that the mutual attraction or repulsion of two electrified bodies is directly proportional to the quantity of electricity on the other, and diversely proportional to the square of the distance between them. Coulomb ascertained that electrified bodies, when insulated, gradually lose their electricity by the conduction of the surrounding atmosphere, which is never free from moisture, and by the imperfect insulation afforded even by the best electrics. He also determined, in a more decided manner than had previously been done, that electricity is accumulated on the surfaces of conducting bodies only, and never penetrates the interior.

* History of Electricity, p. 247.

A few years before the invention of the torsion-balance, the electrophorus of M. Volta had been added to the apparatus of the electrician. This instrument is principally valuable as exemplifying in a remarkably striking manner the action of induced electricity. When an insulated metal plate is brought into contact with a cake of resin, or with any other flat electric surface when excited, the insulated plate is immediately rendered electrical; but not, as might be supposed, by electricity communicated directly from the resin, but by induction. The two sides of the metal disc become in opposite states of electricity; that one nearest to the electric being of the contrary kind to that of the electric itself. Supposing a cake of resin to be employed, the metal surface in contact with it is positively electrified, and the other side negatively. If when thus in contact, the finger, or any other conducting body, be brought near the plate, the negative electricity passes off in a spark, and the plate being then lifted up by the insulating handle, it will be found to be electrified positively; and so strongly that sparks nearly an inch long may be taken from it. In this manner, by a succession of contacts, electricity may be developed sufficient to charge several Leyden jars without sensibly diminishing the electricity of the excited resin.

The principal remaining incidents in the progress of electric science to the end of the 18th century were the researches of Lavoisier, La Place, and others relative to electrical excitement by the evaporation of fluids, and by the solution of solids in acid menstrua. In every instance of sudden change of state, and of rapid chemical action under such circumstances, electricity was developed. These experiments by the French chemists indicated the close connexion between electricity and chemical action, which subsequent investigations have proved to possess a most important bearing on the development of electricity.

CHAPTER III.

Discovery of Galvanism, and the circumstances that led to it—Galvani's erroneous notions of the exciting cause—Volta's investigations—Invention of the Voltaic pile—Commencement of the science of Voltaic electricity—Various Voltaic batteries—Theories of their action—Investigations by Sir Humphery Davy—Decomposition of the alkalies and earths—The experiments that led to the discovery founded on a hoax—Prodigious Voltaic batteries constructed—Napoleon Bonaparte's experience of their power—Unsuccessful application of Voltaic electricity by Sir H. Davy.

As the last century drew to its close, a new era commenced in electric science of far more importance to its development than any of the preceding stages of advancement. The first glimmering of light in the new direction, as in most of the preceding discoveries, arose from fortuitous circumstances; and it is worthy of notice that this discovery was founded on ignorance of the principle on which it depended.

Galvani, an anatomical professor at Pavia, has the merit of being the originator of that branch of electric science which was for many years termed *galvanism*. One account of the discovery represents that his at-

tention was first directed to the subject by his wife and a pupil, who had observed the limb of a frog convulsed when touched by a knife near to an electrical machine. Madame Galvani is made more conspicuous in the matter by the assertion that she was an invalid, and that the presence of the limbs of frogs in the dissecting-room was owing to her having ordered the frogs as a delicacy for her dinner. It is stated, however, by Galvani, in a work published at Bologna in 1791 for the Institute of Sciences,* that he was dissecting a frog on a table whereon stood an electrical machine, when the limbs suddenly became convulsed by one of his pupils touching the crural nerve with a dissecting-knife. This occurred at the instant that a spark was taken from the conductor of the machine. The experiment was repeated several times, and it was found to answer in all cases when a metal conductor was connected with the nerve, but not otherwise. Galvani, who entertained the opinion that muscular action is attributable to electricity, looked on this phenomenon as a confirmation of that opinion, and pursued the inquiry with great zeal. Having tried various experiments successfully with the electrical machine, the electrophorus, and other artificial means of exciting electricity, he also tried the effect of atmospherical electricity. He attached the legs of frogs and of warm-blooded animals to a pointed conductor fixed at the top of the house, and found that they were violently convulsed by every flash of lightning. Similar effects, though not so strong, were also produced by atmospherical electricity, when there was no thunder-storm. In the prosecution of these researches he suspended some frogs, on metal hooks fixed in the spine, from the iron railings of his garden, and observed the contractions in all states of the weather, when he connected the hook with the iron rails. He therefore supposed that the effect might be produced independently of the atmosphere; and he found, on experimenting with a frog in his room, that whenever a metallic connection was made between the external muscle and the crural nerve, the limbs became convulsed. As this effect was produced without any apparent external excitement of the electric fluid, Galvani inferred, in accordance with his preconceived hypothesis, that the muscular contraction was caused by animal electricity, that the muscle and the nerve were in the condition of the inside and the outside of a charged Leyden jar, and that the metallic connection merely served the same purpose as a discharging wire, by giving the two electricities the means of combining.

It has been observed, that had Galvani been more accustomed to electrical experiments, he would have paid no attention to the convulsion of the frog's limb, and would have considered it merely as the customary effect of electricity when passed through an animal conductor. The same fact had, indeed, been observed by others, and thus disregarded. But Galvani, impressed with his idea of muscular action being caused by animal electricity, brought the fact prominently forward. The electricians who had observed the same without regard, formed, indeed, more correct notions of the cause than Galvani, but by his endeavour to establish an error, he was the means of elucidating a most important truth.

In the meantime, the extraordinary physiological effects produced by such insignificant means gave countenance to Galvani's notion that they

* Aloysii Galvani de viribus electricitatis in motu musculari commentarius.

were produced by animal electricity, and physiologists eagerly seized hold of this assigned cause of vital energy, the agency of the "nervous fluid" being relinquished for that of electricity. Volta, however, manfully combated the opinion that the exciting cause resided in the animal fibres, and contended that the muscular contractions produced when the muscle and the nerve were connected by a metal, arose from the contact of the metal itself, and was entirely independent of animal electricity. In support of this opinion was adduced the peculiar sensation occasioned by the contact of a piece of silver with a piece of lead or zinc, when both are placed upon the tongue, a fact which had been noticed by M. Sulzer in 1762, without attracting much attention.* Volta conceived that by combining a series of silver and zinc plates, he should be able to add to the electrical effect by increasing the number of metallic contacts. He therefore piled up a series of plates, consisting of zinc and silver alternately, with interposed pieces of wet cloth, and obtained the expected accumulation of electrical force.

The results of Volta's important experiments were announced in a letter to Sir Joseph Banks, which was read before the Royal Society on the 26th of June 1800. In that communication M. Volta stated that he had obtained some striking results from electricity excited by the simple mutual contact of different kinds of metals, and even by the contact of other conductors different among themselves, whether liquid or containing some fluid to which they were indebted for their conducting properties. The principal results he stated were, "the construction of an apparatus which resembles, in its power of producing electric shocks and other electrical phenomena, the Leyden jar, and still more closely electrical batteries when feebly charged; which operate also without ceasing, and possess a perpetual impulsion." This apparatus consisted of discs of silver and zinc, about one inch diameter, and small discs of card or parchment, moistened with water or with a solution of common salt. The metal discs were piled upon one another alternately, and between every two was applied one of the moistened cards. With a series of twenty of these pairs of discs, he stated that Cavallo's pith ball electrometer, aided by a condenser, was affected to the extent of from 10 to 15 degrees; that when wires connected with the upper and lower plates of the series were brought together, sparks were emitted; and that the apparatus would give a shock through the fingers. With a series of fifty pairs, the shock, he stated, became so powerful as to reach to the shoulders, and when passed through a single finger, the pain was too great to be borne. Volta, it is probable, exaggerated the effects of this diminutive apparatus, and he evidently mistook the partial combustion of the metallic wires, on making contact, for the electric spark,

* The following extract from M. Sulzer's writings marks the first dawn of this important discovery:—

"When two pieces of metal, one of lead and the other of silver, are so joined together that their edges make one surface, a certain sensation will be produced on applying it to the tongue, which comes near to the taste of martial vitriol; whereas each piece by itself betrays not the slightest trace of that taste. It is not improbable that, by a combination of the two metals, a solution of either of them may have taken place, in consequence of which the dissolved particles penetrate into the tongue; or we may conjecture that the combination of these metals occasions a trembling motion in their respective particles, which, exciting the nerves of the tongue, causes that peculiar sensation."—*Theory of Agreeable and Disagreeable Sensations;* Berlin, 1762.

which can only be produced by a much more numerous and powerful arrangement than Volta employed.

Volta had been a long time in obtaining the results communicated in his letter to Sir Joseph Banks, and having experienced the inconvenience of the pile, he contrived an arrangement called by him *à couronne de tasses,* in which zinc and copper plates connected together by wires were immersed in different cups containing a solution of common salt. A series of these cups formed a very efficient battery, and he was enabled, as he said, to produce effects which, though considerably less active than a battery of Leyden jars, possessed nevertheless immense power. The close resemblance of the electricity evolved in this manner to that of the torpedo did not fail to strike Volta, who accordingly called his apparatus the *organe électrique artificiel.*

The discoveries of Volta, though far surpassing those of Galvani, were at first considered subservient to the purpose of giving greater effect to the experiments of the latter. The increased muscular energy that could thus be given to the limbs of recently killed animals excited amazement and awe, and itinerant lecturers in all parts of the kingdom exhibited these wonders to collected multitudes; nor were charlatans wanting, who by tricks of legerdemain gave a still more marvellous character to the really extraordinary effects of this newly discovered agent. The importance of the exciting power thus became merged in the effects it produced. Because the battery of Volta was at first chiefly employed to illustrate the discovery of Galvani, it received the name of the "Galvanic battery," which it for a long time retained, and the new branch of science founded upon it was still more unjustly termed Galvanism.

As this new mode of exciting electricity was announced in 1800, we may date from the beginning of the present century the commencement of the science of voltaic electricity. In the early days of this discovery it was not determined whether to consider it as a modification of the electric fluid, or as a distinct agent excited by the contact of metals, though the researches of the most eminent electricians have since established the identity of the two.

The points of resemblance between the two electricities are, that both produce similar effects on the nerves that contract the muscles and occasion the electric shock, which may be communicated through a great number of persons instantaneously; that the same substances are conductors and non-conductors of both kinds of electricity; that both possess the power of igniting and heating; that sparks are emitted by the voltaic battery when great numbers of plates are used to increase the intensity of the force: that the phenomena of attraction and repulsion are common to both, and by both chemical decomposition can be effected.

The differences between voltaic and frictional electricity consist in the continued duration of the effects of the former, and in the different states of intensity in which they are evolved: voltaic electricity being evolved in great quantity at a low degree of intensity, whilst the quantity of frictional electricity excited is comparatively very small, but at a high degree of intensity. These different conditions in which the electricities of the voltaic pile and of the electrical machine are excited, occasion a difference in the phenomena of each. It was not, for example, an easy matter to make an arrangement with frictional electricity for the exhibition of che-

mical decomposition, nor could the electric spark be readily made to force itself through even the smallest space of air from a voltaic battery. The experiments of Dr. Wollaston, of Sir Humphrey Davy, and more recently of Dr. Faraday, have, however, removed all doubts respecting the power of frictional electricity to effect chemical decomposition; and Mr. Crosse, with a water battery of 2000 cells, has evolved voltaic electricity possessing sufficient tension to force itself in a rapid succession of sparks through a small intervening space of air.

Numerous attempts were made soon after the announcement of Volta's discovery and invention to improve the form of apparatus, and these endeavours have been continued with more or less success to the present day, though the arrangement *à couronne de tasses,* modified and rendered more compact, is still that most frequently adopted. The only marked variations in the principle of construction which require to be noticed in this part of our work, were the increase of the quantity of electricity by enlarging the size of the plates, so as to communicate greater heating power to the battery, and the increased intensity produced by greatly adding to the number of combinations, as in the column of De Luc. The latter arrangement deserves notice also, from the circumstance that no moisture is applied to produce the effects. This apparatus, as improved by Zamboni, consists of paper, on one side of which is pasted finely laminated zinc, and the other is covered with powdered black oxide of manganese. The paper so prepared is cut into discs about one inch in diameter, which are arranged over one another with the zinc sides placed in the same direction, and they are enclosed within a glass tube after having been pressed together. This instrument, when it consists of a pile of 10,000 discs, exhibits a constant excitement of electricity of considerable intensity. It deflects the gold leaves of the electrometer, yields small sparks, charges a Leyden jar, and attracts and repels light substances in the manner of an excited glass tube. Its action continues without intermission for months, and even for years. A pile consisting of 1000 prepared paper discs may be arranged so as to keep a small pendulum vibrating between its opposite poles, and it thus approaches more closely than any other invention to perpetual motion.*

Theory of contact.

In this instrument the paper is the substance interposed between each pair of metallic exciters, and though apparently dry, it contains sufficient moisture in all states of the atmosphere to act as a conductor.

The exciting cause of electricity in the voltaic battery was conceived by Volta to be the contact of dissimilar metals. The liquid wherein the plates are immersed was regarded merely as the conductor of electricity from one pair to another, and the advantage of employing saline solutions in preference to water was attributed to their superior conducting power. This theory was quickly combated by Dr. Wollaston, who ascribed the effect entirely to the chemical action of the solution on the zinc. That opinion was afterwards ably confirmed by Sir Humphrey Davy, who proved, by various experiments, that chemical action is essential to the excitement of voltaic electricity. He shewed, also, that a voltaic battery

* We ought perhaps to except the German atmospherical clock, shewn at the Great Exhibition, in which the variations in the pressure of the atmosphere were applied as the motive power.

may be constructed without any metallic element. In November 1801, he formed a battery of this kind, which consisted of ten pieces of well-burnt charcoal, with nitric acid and water arranged alternately in wine-glasses, which produced all the effects usually obtained from an alternate arrangement of zinc, silver, and water. More recently, Dr. Faraday has shewn, that when the usual elements are employed, voltaic action may be excited without contact of the metals. Notwithstanding these evidences of chemical action, the contact theory continues to be the favourite hypothesis with philosophers on the continent, and the action of De Luc's column, without the perceptible presence of any fluid, has given support to their arguments.

Whether chemical action be, or be not, the exciting cause of voltaic electricity, the agency of that power in disturbing chemical affinities is one of its most remarkable and important characteristics. Nor did this extraordinary power long lie dormant. Two months before Volta's communication was read before the Royal Society, Messrs. Nicholson and Carlisle effected the decomposition of water by Volta's apparatus, which had been described in foreign journals; and Sir Humphrey Davy, improving on these experiments, succeeded in producing the oxygen and hydrogen gases from separate portions of water, in different glasses, connected together by moistened threads. Following up these experiments, he decomposed several compound bodies, and in every case he found that when substances containing sulphur or metal combined with oxygen were operated on, the sulphur and metal appeared at the negative end of the battery, and oxygen at the positive end. He was led to infer from these and similar experiments with the voltaic battery on the decomposition of bodies, that electrical action is identical with chemical affinity.

In pursuing his investigations into the nature of the action of the voltaic battery, Sir Humphrey Davy ascertained that the intensity increases with the number of the plates, and that the quantity of electricity excited is dependent on their size; a fact which was subsequently verified by Mr. Children, who with a single pair of very large plates of zinc and copper was enabled readily to melt the most infusible metals.

Armed with such a powerful decomposing agent as the voltaic battery, numerous chemical experimentalists pursued their researches into the elementary constituents of bodies with great ardour. Dr. Henry decomposed several of the acids, and resolved ammonia into its proximate elements. Berzelius transferred the elements of neutral salts to their respective poles: the acids being collected at the copper end of the battery, and the alkalies and earths being attached to the zinc terminus. These and various other results were published in the journals, and served to give additional stimulus to electro-chemical investigations.

Whilst scientific men were anxiously looking for important results from the inquiries thus sedulously pursued, there appeared in the *Philosophical Journal* a letter signed E. Peel, of Cambridge, announcing that, in his experiments on the decomposition of water, he had invariably found the pure water with which he commenced operating impregnated with common salt. This announced generation of salt by the action of the voltaic battery excited a lively sensation amongst philosophers in most parts of Europe. Some applied themselves to verify the experiment, whilst others speculated on the new light thus thrown on the cause of the sea

being salt. The announcement was, however, soon afterwards detected to be a hoax, there being no person of the name of Peel at Cambridge. In the meantime, while the concocter of this practical joke was probably enjoying its success, experimentalists had actually obtained the results which he had published as a wildly extravagant notion. It was ascertained that distilled water, after having been acted on for some time by a voltaic current, contained in every case an appreciable quantity of salt. This proved a most perplexing discovery. The apparent creation of matter by voltaic action was as difficult to account for, as in later days has been the apparent creation of living insects by the same agency. Sir Humphrey Davy entered ardently into the investigation, and after a continued series of carefully conducted experiments, he ascertained that the salt or earthy matter eliminated was extracted from the substance of the threads employed, or was owing to the partial decomposition of the glass vessels in which the experiments were conducted. The more careful he was in avoiding these sources of error, the water became more free from saline particles; and when fibres of pure asbestos were substituted for thread, and agate cups for glass, no trace of alkali or earthy matter was to be detected in the water.

It was in consequence of these researches, undertaken for the purpose of shewing that the results of the experiments on the Continent were as illusory as the *ignis fatuus* which lighted the way to them, that Sir Humphrey Davy was led into the course of experiments which terminated in his brilliant discovery of the metallic bases of the alkalies and earths. The circumstance that the origin of one of the most important discoveries in science may be thus traced to the senseless trick of an unknown individual, presents a remarkable feature among the curiosities of science, and affords ample food for reflection to the speculative philosopher on the elimination of valuable truths from falsehood and error.

It is not strictly within our province to notice the labours of chemical experimentalists; but the decomposition of the alkalies and earths exhibits such striking examples of the chemical power of voltaic electricity, that the discovery of their bases by its means may be fairly considered to belong to the history of the progress of electric science.

From the first announcement of the discovery of the voltaic battery, Sir Humphrey Davy foresaw the vast importance of its agency in chemical researches. In a note-book dated August 6th, 1800, he writes: "I cannot close this notice without feeling grateful to M. Volta, Mr. Nicholson, and Mr. Carlisle, whose experience has placed such a wonderful and important instrument of analysis in my power."* In his first Bakerian lecture six years afterwards, he expresses the hope that "the new mode of analysis may lead us to the discovery of the *true* elements of bodies, if the materials acted on be employed in a certain state of concentration, and the electricity be sufficiently exalted. For, if chemical union be of the nature which I have ventured to suppose, however strong the natural energies of the elements of the bodies may be, yet there is every probability of a limit to their strength; whereas the powers of our artificial instruments seem capable of indefinite increase."†

* Memoirs of the Life of Sir Humphrey Davy, Bart., by John Davy, M.D.
† Ibid.

In conformity with the notion of counteracting chemical attraction by electrical agency, he instituted a series of experiments on potass with a view to its decomposition; the compound nature of the alkalies having been for some time suspected. At first he experienced great difficulty in getting the electric current to act on the potass, which when in a solid state is a non-conductor of electricity, and when acted on in solution the water only was decomposed. The first successful results were obtained by employing fused potass; inflammable matter was then developed, which burst into flame the instant it was formed. The complete success of the investigation occurred on the 6th of October. The following brief account of the discovery is contained in a manuscript of a lecture delivered at the Royal Institution.

"*Experiments.* Then a piece of potass, moistened, and to my great surprise I found metallic matter formed.

"Oct. 6th. This matter instantly burnt when it *touched water*, swam on its surface, reproducing potass. In dry oxygen gas likewise it burnt into perfectly dry potass."*

"The extreme delight which he felt when he first saw the metallic basis of potass," observes Sir Humphrey Davy's brother, "can only be conceived by those who are familiar with the operations of the laboratory, and the exciting nature of original research; who can enter into his previous views, and the analogies by which he was guided; and can comprehend the vast importance of the discovery in its various relations of chemical doctrine; and, perhaps, not least, who can appreciate the workings of a young mind with an avidity for knowledge and glory commensurate? I have been told that when he saw the minute globules of potassium burst through the crust of the potass, and take fire as they entered the atmosphere, he could not contain his joy—he actually danced about the room in ecstatic delight, and that some little time was required for him to compose himself sufficiently to continue the experiment."

The battery power employed by Sir Humphrey Davy in effecting this brilliant result consisted of a combination of twenty-four plates of copper and zinc twelve inches square, one hundred plates of six inches, and one hundred and fifty of four inches. As it is a peculiar property of the voltaic battery that the quantity of electricity transmitted by a series of plates is dependent on the size of the smallest plate of the series, it follows that the power thus brought to bear was equal to that of a battery of 274 pairs of plates of four inches square. The managers of the Royal Institution afterwards placed at his disposal a voltaic battery of 600 double plates four inches square: and a still larger battery, consisting of 2000 plates, was constructed by subscription for his use.

The important discoveries of Sir Humphrey Davy, by means of the voltaic battery, caused increased attention to be paid to that valuable agent in chemical analysis, and voltaic batteries were made on a larger scale than any that had previously been constructed. It is related that when Napoleon heard of the decomposition of the alkalies by an English philosopher, he angrily questioned the *savans* of the Paris Institute why the discovery had not been made in France. The excuse alleged was the want of a battery of sufficient power. He immediately commanded one to

* Memoirs of the Life of Sir Humphrey Davy, Bart., by John Davy, M.D.

be made; and when completed he went to the Institute to see it. With his usual impetuosity, the Emperor seized hold of the wires, and before he could be checked by the attendant, applied them to his tongue. His imperial majesty was rendered nearly senseless by the shock; and as soon as he recovered from its effects, he walked out of the laboratory with as much composure as he could assume, not requiring further experiments to test the power of the battery; nor did he ever afterwards allude to the subject.*

With the powerful voltaic batteries that were then constructed, the course of investigation into the constituent parts of bodies was steadily pursued; and numerous compound substances yielded up their elements to the decomposing influence. Substances that had resisted the greatest heat of the furnace were readily fused, and even the diamond was burnt in the voltaic arc, and its chemical character was identified with carbon.

We must not omit to notice the attempt made during this period by Sir H. Davy to practically apply voltaic electricity for the prevention of the corrosion of the copper sheathing on ships. He had ascertained, when two metals in contact are immersed in a saline solution, that whilst an increased action takes place on one of the metals, caused by contact, the action of the solution on the other is diminished. Copper, for example, undergoes corrosion in sea-water; but when zinc is in contact with it the corrosion of the copper ceases. Sir H. Davy applied this principle to copper sheathing, by protecting it with strips of zinc. The experiment succeeded scientifically by preventing corrosion, but it practically failed; for the copper thus protected became covered with sea-weed and shell-fish, which do not adhere to the corroded surface. Sir H. Davy was deeply mortified at the failure of this experiment in a practical point of view; but it has led to the discovery of an alloy of copper that answers the purpose intended very successfully.

CHAPTER IV.

Discovery of Electro-magnetism—Increase of the force by coils of wire—Electro-magnets—Tangential action of the force—Invention of the Galvanometer—Its application to telegraphic purposes—Discovery of Magneto-electricity—Magneto-electrical machines—Thermo-electricity—Faraday's experimental researches—Introduction of new terms—Daniell's constant battery—Discovery of the electrotype process—Development of electricity from high-pressure steam—Present state of electric science.

THOUGH the investigations, conducted with the powerful means at command, elucidated many interesting facts, no striking incident occurred for several years; and Dr. Bostock, in his *History of Galvanism*, appears to have considered that discoveries by the agency of the voltaic battery had reached their end. His words are: "It may be conjectured that we have carried the power of the instrument to the utmost extent of which it admits; and it does not appear that we are at present in the way of making any important additions to our knowledge of its effects, or of

* Dr. Paris's Life of Sir Humphery Davy.

obtaining any new light on the theory of its action." This was written in 1818; and in the next year a new light—almost as brilliant as any of the preceding flashes that had illumined its progress—was thrown on electric science by the discovery of electro-magnetism.

That a close relation subsisted between electricity and magnetism had been known from an early period of its history, and the identity of the two had formed a subject of discussion.

Franklin and his contemporary electricians had communicated magnetism to small bars of steel by the charge of an electrical battery; and the power it exerted in destroying and reversing polarity was also known.

It may be mentioned, as an indication that the question of the probable identity of magnetism and electricity excited considerable attention, that in 1774 the Electoral Academy of Bavaria proposed as the subject of a prize-essay: "Is there a real and physical analogy between electric and magnetic forces; and if such analogy exists, in what manner do these forces act on the animal body?" Though the prize was gained by a professor who maintained that the two powers were essentially distinct from each other, there were not wanting competitors who as strenuously maintained that the forces were the same, though modified by special circumstances. The impression, indeed, of the identity of electrity and magnetism continued very strong; and it seems a remarkable omission in the investigations of philosophers, especially after the discovery of the voltaic pile, that no well-conducted experiments were undertaken to ascertain more closely the relations between the two forces.

Professor Œrsted of Copenhagen, to whom the world is indebted for the discovery of this new and practically useful department of science, published a work in 1807, in which he described the analogies between magnetism and electricity, wherein there occurs the following remarkable passage: "In galvanic action the force is more latent than in electricity; and it is still more so in magnetism than in galvanism. It is necessary, therefore, to try whether electricity in its latent state will not affect the magnetic needle." It does not appear, however, that Œrsted actually tried the experiment indicated in his book; nor does any one else seem to have made the trial, though we now know that the question would have been determined by merely placing a magnetic needle over the wire connected with a voltaic battery. It was not till 1819, twelve years after he had pointed out the way to others, that Œrsted followed the course he had indicated, and by bringing a magnetic needle in the direction of a voltaic current, ascertained that the conducting wire is itself magnetic. He found also that the nature of the conducting medium is immaterial to the result, and that whether the voltaic circuit be compelled through metals or through a fluid, the magnetic needle is equally affected; being deflected in one direction when placed over the conductor, and in the opposite direction when under it.

The discovery was no sooner made known than all those who were engaged in scientific researches throughout Europe pursued the inquiry with diligence, and continually elicited additional facts, which bestowed increased importance on this correlative branch of electric science. MM. Ampère and Arago, of the French Academy of Sciences, having discovered that the direction of the magnetic force is tangential to the wire, succeeded in multiplying the power by twisting the conducting wire into

a spiral coil. In this manner the action of the voltaic current was frequently repeated within a small area; and by adopting this arrangement sufficient magnetic force was obtained to attract iron filings to the coil, and a steel bar placed within it was quickly magnetised.

In September of the same year that Professor Œrsted's discovery was known, M. Arago communicated to the French Academy that the electric current possesses the power of imparting magnetism to iron and steel; and Sir Humphrey Davy ascertained independently the same important fact, though somewhat later.

It was ascertained that the coil of wire through which the voltaic current was transmitted in these experiments operated in all respects like a magnet; but that the action ceased instantaneously when the current was interrupted. The power of the coil was found to be greatly augmented by introducing a bar of iron within it, to which bar magnetic properties were instantly communicated; but if the iron were pure and soft, those properties ceased the moment that the electric circuit was broken. The nearer the whorls of the coil were brought together without touching, the effect was found to be more concentrated. To prevent the communication of the electricity laterally in the folds of the coil, the wire was insulated; by varnish in the first instance, and afterwards by winding silk or cotton round it, to prevent metallic contact; that slight degree of separation being sufficient to prevent the conduction of voltaic electricity.

The insulation of the wire, trifling as the improvement appears to be, afforded the means of increasing the power of electro-magnetism to a most astonishing degree. Not only could the wire of the coil be twisted close together, but it could be wound upon itself many folds in thickness, each additional layer of wire giving increased magnetic effect. In this manner electro-magnets could be formed with sufficient attractive power to lift upwards of a ton; yet this attraction, so far exceeding that of any artificial magnet that can be made by other means, ceases the instant that the connexion is broken between the coil of wire surrounding it and the voltaic battery.

Professor Œrsted having ascertained that the electric current passing through a conducting wire acts on the magnetic needle transversely in every position in which it can be placed, he inferred that the magnetic effect of the electric current is to give a circular motion round the wire. M. Ampère entertained the same view, and proved by experiment that the conducting wires of two galvanic currents, if free to move, would mutually attract each other. Dr. Faraday contrived an ingenious apparatus for shewing not only the rotation of a magnet round a conducting wire, but the rotation of a conducting wire round a magnet. This seemed to confirm the previously announced theory of M. Ampère, that magnetism is induced by circular currents round the magnetised bodies; and it appeared also to introduce an anomaly in the action of moving forces, which are always exerted in straight lines. The apparent anomaly may probably be removed by resolving the circular motion, like that of all other bodies moving in curves, into the operation of two forces acting in different directions.

The communication of rotary motion by electro-magnetism, and the powerful attractive force called into action in electro-magnets, were considered to indicate a new and valuable source of motive power, that could be applied directly to the production of rotary motion. Numerous at-

tempts were made to apply the power to useful purposes as a substitute for steam, and the notion is not yet abandoned; though there have been hitherto no practical results that lead us to expect the object will be attained.

A most valuable instrument in conducting researches in voltaic electricity was contrived shortly after the discovery of the magnetic influence of the voltaic battery, and depending on that influence for its action. The low state of tension of voltaic electricity prevents it from being appreciable by the ordinary electrometer, excepting when the intensity is increased by the combination of a series of plates. An attempt was made by Mr. Pepys, in the very infancy of voltaic electricity, to obtain an indication of its force by increasing the sensibility of the gold-leaf electrometer; and he so far succeeded that with a pile consisting of a series of eighty pairs of plates, he produced a very decided deflection of the gold leaves, but the instrument afforded no indication of electricity with a much smaller number.*

The experiment that discovered electro-magnetism, at the same time pointed out the means of measuring its force. The deflection of the magnetic needle by the conducting wire of the battery afforded a highly sensitive indicator of the excitement of voltaic electricity. When the method of multiplying the force by means of folds of insulated wire twisted into a spiral coil became known, it was quickly made available for giving increased sensibility to the magnetic needle; and in this manner galvanometers were constructed of such extreme delicacy as to detect the minutest portions of electricity.

The invention of the galvanometer suggested the application of that instrument to the purpose of communicating telegraphic signals. That plan has, after numerous improvements, attained such a degree of perfection, that by the varied deflections of two galvanometer-needles communications are transmitted between places hundreds of miles asunder almost as quickly as they can be written down. The idea of employing electricity, though in a different manner, for telegraphic purposes was indeed by no means new. So far back as 1774 a plan was proposed of transmitting signals through wires by causing pith balls to be deflected when an electric discharge was made. It was in 1830 that M. Ampère suggested the application of deflected needles, and in 1837 Mr. Alexander of Edinburgh exhibited in London the first electric telegraph on that principle. The plan was, however, impracticable, as it required a separate magnetic needle and a separate insulated wire for each letter of the alphabet.

We shall not attempt at present to follow the course of telegraphic invention, which will be fully described when we come to treat of the practical applications of electricity. It is sufficient in this place to observe that since the application in 1837 of M. Ampère's suggestion, there have been at least one hundred patents obtained for different modes of telegraphic correspondence, most of them based on the same principle, or depending for their action on electro-magnetism; and that by employing electro-chemical agency, communications may now be instantaneously transmitted with a single connecting wire ten times faster than any one can write.

* Philosophical Journal, June 1801.

In pursuing investigations into the phenomena of electricity, Dr. Faraday was led to infer that as a current of electricity induces magnetism, the magnetic force would induce electricity. Aided by the multiplying power of the coil, and by the sensitiveness of the galvanometer, he was enabled to prove the correctness of the inference, and to establish the foundation of the branch of electric science termed *magneto-electricity.* His experiments were conducted in the year 1831, and shortly produced most important results.

The induction of electricity by magnetism was in the first instance shewn by connecting a hollow coil of wire with a galvanometer, and then inserting within the coil a powerful steel magnet. Whilst the magnet remained in the coil, the galvanometer gave no indication; but on quickly withdrawing the magnet, the needle was instantly deflected. A similar temporary deflection was observed to take place when the magnet was quickly introduced; and in November of the same year Faraday derived still more complete evidence of induction by eliciting an electric spark. The effect produced by inserting and withdrawing the permanent magnet into and out of the coil of wire was found to be greatly augmented when an electro-magnet was substituted for the permanent steel one, and contact with the voltaic battery was rapidly made and broken. The instant that the iron was rendered magnetic, by making contact with the battery wires, the temporary transmission of electricity took place through the coil of wire which surrounded it; and by making and breaking contact with great rapidity, there was a continuous succession of electrical effects.

The electricity thus induced in what is now termed the *secondary current* was ascertained to be of a high degree of intensity, and to pass in a contrary direction to that of the primary current. The phenomena became more marked when the length of wire in the coil of the secondary circuit was increased; so that by adding to its length, a degree of intensity was obtained equal to that of a numerous series of plates of a voltaic battery, though the primary exciting cause which communicated magnetism to the iron was only a single pair.

By improved mechanical arrangements, the principle of electro-dynamic induction brought to light by the experiments of Faraday has been made to operate as a most powerful exciter of electricity. Magneto-electric machines have been constructed with permanent steel magnets, that possess the power of the most intense voltaic batteries; giving shocks that are insupportable, emitting sparks, and operating as active decomposing agents. The instrument is also capable of being arranged as an exciter of quantity-electricity in a comparatively lower state of intensity, so as to fuse wire, induce magnetism, and exhibit the other phenomena common to the voltaic electricity excited from a pair of plates of large size. This mode of exciting electricity, independently of the friction of electrics or of chemical action, seemed to present the advantage of procuring a powerful agent with comparatively little labour and no cost of materials; and attempts have been consequently made, with considerable success, to apply it to practical purposes, which we shall have subsequently to notice.

Though the world is indebted to Faraday for the development of the induction of electricity from steel magnets, the fact that electrical effects could be so elicited had been imperfectly discovered at the beginning of

present century; but it had then no results, and was soon forgotten. The only notice of that discovery which we have been able to find occurs in the *Monthly Magazine* for April 1802, to this effect:—"Galvanism is at present a subject of occupation of all the German philosophers and chemists. At Vienna an important discovery has been announced—an *artificial magnet*, employed instead of Volta's pile, decomposes water equally well as that pile, or the electrical machine, whence it has been concluded that the *electric, galvanic,* and *magnetic* fluids are the same." It is curious to observe how thus in the course of time discoveries and inventions that have passed away and been disregarded, because circumstances were not then suited to their development, are revived in later years either by accident or original research and ingenuity, and become important elements in the advance of science and the progress of civilisation. We may notice also, in the preceding announcement, that the fact of the correlative nature of the three forces, which has been established by the persevering investigations of modern philosophers, was anticipated fifty years ago.

For the purpose of not breaking in upon the outline of the progress of electro-magnetism, we have passed by other discoveries of considerable importance to which it is necessary to revert.

An additional source of electricity was developed, in the year following the discovery of electro-magnetism, by Dr. Seesbeck, who communicated to the Academy of Berlin that he had succeeded in exciting electricity by the disturbance of temperature. He ascertained that two metals—antimony and bismuth being the most effective—when soldered together at their extremities and then heated at the joints, whilst the other ends are kept cool, produce a decided deflection of the galvanometer. This property of the metals has no reference to their efficiency in voltaic arrangements, nor to their powers of conducting electricity. The effects first produced by Dr. Seesbeck were derived from the combination of four bars of antimony and bismuth in the form of a rectangular frame, one corner of which was heated and the other covered with ice.

Messrs. Nobili and Melloni succeeded in constructing thermo-electric piles by the combination of a series of bars of metal soldered together. With this apparatus most of the ordinary electrical phenomena have been produced, including the appearance of the electric spark, the decomposition of water, and the communication of magnetic properties. The quantity of electricity evolved by this means is, however, very small; and thermo-electricity has yet assumed scarcely any importance; though some philosophers are disposed to ascribe the magnetism of the earth to thermo-electric currents circulating round the globe.

Long previous to the discovery of Dr. Seesbeck, the influence of heat in exciting electricity had been ascertained, though the knowledge was then limited to its effects on crystalline bodies. In 1717 M. Lemery exhibited to the French Academy of Sciences a stone, supposed to be tourmalin, which attracted light substances; and the Duke de Noya performed many electrical experiments with that crystalline body; but it was Æpinus who first shewed that heat was necessary to produce the phenomena. The Abbé Haüy, celebrated for his researches in crystallography, found that the electricity of the tourmalin decreased rapidly from the poles of the crystal, and that when broken, each fragment is electrical, and in a similar polar condition. He afterwards discovered that topaz and many

other crystals of similar conformation exhibit signs of electricity when heated. Sir David Brewster has more recently discovered that the same property extends also to the crystals of many salts.

The crystalline bodies which could thus be acted on by heat were called pyro-electrical. As their phenomena depend on the same exciting cause as that which produces electricity in variably expansive metals, they may be considered as belonging to thermo-electricity; and we have deferred noticing them till they could be classed together with the crystalline metals that become electrical by heat.

Professor Faraday commenced in 1832 a series of experimental researches into the nature of electro-chemical action, the results of which were published from time to time in the *Philosophical Transactions* from 1833 to 1844, and constitute most valuable contributions to electric science. One important point which these researches tend to prove is, that in the course of electro-chemical decomposition the elementary atoms of the compound substance acted on are transferred from atom to atom of the fluid, in a continuous chain from one pole of the battery to the other; the conduction of voltaic electricity through fluids being thus dependent on a successive series of decompositions and recompositions in opposite directions. Another important point which they may be considered to have established is, the law of definite electro-chemical action;—that "for a constant quantity of electricity, whatever the decomposing conductor may be, whether water, saline solutions, acids, fused bodies, &c., the amount of electro-chemical action is also a constant quantity, *i. e.* would always be equivalent to a standard chemical effect founded upon ordinary chemical affinity."*

According to the views of Professor Faraday, electro-chemical decomposition is occasioned by "an internal corpuscular action excited according to the direction of the electric current; and that it is due to a force either superadded to or giving direction to the ordinary chemical affinity of the bodies present." He conceives, therefore, the effects of the decomposition "to arise from forces which are *internal* relative to the matter under decomposition—and not *external,* as they might be considered if directly dependent upon the poles."

To express these views of the action and direction of the forces exerted during electro-chemical decomposition, Faraday conceived that the terms previously employed were inefficient; he therefore determined to introduce a nomenclature suitable to the modes of action indicated. He obtained the assistance of two classical friends to aid him in this undertaking, and the result was the application of several Greek terms to denote processes and things which had been long known by other names. It may seem presumptuous to question the propriety of the course adopted by that eminent philosopher, but so strong is our impression of the injurious effects of multiplying terms requiring constant explanation, that we venture to express our conviction that it has tended unnecessarily to encumber the study of electricity.

The nomenclature of every science ought, in our opinion, to be extremely simple, and, if possible, clearly expressive of the character or action of the thing or process designated; nor do we perceive any equi-

* Experimental Researches in Electricity, ¶ 505.

valent advantage gained by the adoption of the words of a dead language, which often serve no better purpose than to conceal by their unfamiliar sounds absurd, puerile, or questionable designations. The terms previously in use to express the different electrical phenomena and conditions were so various as to afford ample choice to those who entertain differing views of the nature and actions of the electric fluid. There were "*plus* and *minus*," "positive and negative," "vitreous and resinous," to express the kinds of electricity excited;—and "electrics," "ideo-electrics," "non-electrics," "conductors," and "non-conductors," to indicate the electrical qualities of different substances. When voltaic electricity gave rise to new terms, the copper or zinc "end" of the battery was an intelligible English expression to denote what those more fond of classic names called "terminus," and which afterwards received the name of "pole." Possessed of this abundance of expressions, we do not conceive that any good purpose is answered by adding to the list a number of Greek words and terminations to express supposed analogies in the action of the voltaic battery. Faraday himself had evidently misgivings on the subject; for after explaining the meaning of the new terms, he adds: "I do not mean to press them into service more frequently than will be required; for I am fully aware that names are one thing, and science another;" and he afterwards found it advisable to change some of the terms for "such as were at the same time simple in their nature, clear in their reference, and free from hypothesis."* It is to be wished that he had from the first acted on his own judgment and knowledge, without being guided by his learned friends.

As it is our intention to present a clear and intelligible view of the science of electricity free from unnecessary technicality, we shall endeavour to avoid using any portion of the nomenclature constructed by Professor Faraday's philological friends; but as those terms will be often met with in other works on the subject, they must not be passed by unnoticed. We therefore adopt the following abbreviated explanation by Mr. Noad:†

"What are called the *poles* of the voltaic battery are merely the surfaces or doors by which the electricity enters into or passes out of the substance suffering decomposition; Faraday hence proposes for them the term *electrodes*, from ἤλεκτρον and ὁδὸς, *a way*, meaning thereby the substance or surface, whether of air, water, metal, or any other substance, which serves to convey an electric current into and from the decomposing matter, and which bounds its extent in that direction.

"The surfaces at which the electric current enters and leaves a decomposing body he calls the *anode* and *cathode*, from ἄνα, *upwards*, and ὁδὸς, *a way—the way which the sun rises;* and κατὰ, *downwards*, and ὁδὸς, *a way—the way which the sun sets.* The idea being taken from the earth, the magnetism of which is supposed to be due to electric currents passing round it in a constant direction from *east* to *west*."—"The anode is, therefore, that substance at which the electric current enters; it is the *negative* extremity of the decomposing body; is where oxygen, chlorine, acids, &c. are evolved, and is against or opposite the positive electrode. The *cathode* is that surface at which the current leaves the decomposing

* Experimental Researches in Electricity, vol. i. ¶ 666.

† Lectures on Electricity.

body; the combustible bodies, metals, alkalies, and bases are evolved there, and it is in contact with the negative electrode."—"Compounds directly decomposable by the electric current are called *electrolytes*, from ἤλεκτρον and λύω, *to set free*—to *electrolyze* a body is to decompose it electro-chemically: the elements of an electrolyte are called *iöns*, from ἰὼν, participle of the verb εἶμι, *to go*; *anions* are the iöns which make their appearance at the anode, and *cations* are the iöns which make their appearance at the cathode, and were termed the electro-positive elements."—"Mr. Daniell proposes further to distinguish the doors by which the current enters and departs by the terms *zincode* and *platinode;* the former being the plate which occupies the position of the generating plate in the battery, and the latter of the conducting plate."

We have abstained from noticing the many alterations and improvements in the form and construction of the voltaic battery that have been introduced since the original discovery by Volta, partly because those which are of practical importance will be afterwards described, and partly also because such improvements are not of a character to produce any notable impression on the course of electrical discovery. The "constant" battery of Professor Daniell, however, invented in 1832, requires to be noticed in this place; not only from the distinguishing principles of its action, but from its influence on the discovery of the process of electro-metallurgy.

In the arrangement *à couronne de tasses* of Volta, and in all subsequent contrivances for exciting voltaic electricity, the action of the battery diminished rapidly after the first minute. This was attributable to the combined causes of the collection of bubbles of hydrogen gas and the reduction of the oxide of zinc on the conducting plate. Professor Daniell, with a view to remove these obstructive effects, separated the fluid in which the zinc plate was immersed from that of the copper by an animal membrane, the interposition of which did not retard the passage of the electricity, whilst it effectually prevented the deposition of zinc on the copper plate. The collection of bubbles of hydrogen gas on that plate still, however, operated against the perfect action of the battery. To remove this impediment, the copper plate was immersed in a saturated solution of the sulphate of copper, which was kept separate from the acidulated solution surrounding the zinc plate by the animal membrane. By this arrangement the evolution of hydrogen gas was altogether prevented; for as quickly as detached from its combination with the oxygen of the fluid menstruum by the chemical action on the zinc surface, it seized on the oxygen of the metallic salt, and the metal before held in solution was deposited on the copper plate of the battery. Both of the previously existing causes of the diminution of the force of the battery were thus removed, and by keeping the solution in a saturated state, the action of the voltaic battery was steadily sustained. This "constant" battery of Professor Daniell has proved a most valuable aid in prosecuting researches and in conducting processes that require the continuance of voltaic action for several days with the same amount of force.

The deposition of pure metallic copper from the solution of the sulphate, and the increase in weight of the conducting-plate by the aggregation of particles of copper, could not fail to be observed from the earliest use of the "constant" battery; and Professor Daniell noticed that on the

removal of some portion of the deposited copper, the parts detached presented exact copies of the irregularities of the surface of the plate. Mr. De la Rue, who indeed preceded Professor Daniell in the use of a solution of sulphate of copper as the exciting fluid of an ordinary battery, sent a communication to the *Philosophical Magazine*, published in December 1836, in which he mentions particularly the remarkable appearance of the deposited copper: "So perfect," he observes, "is the sheet of copper thus formed, that on being stripped off, it has the polish and even a counterpart of every scratch of the plate on which it was deposited."

We perceive, therefore, how closely Mr. De la Rue had arrived at the discovery of the electrotype process. It was, in fact, the process itself; conducted, however, without appreciation of its value, and without any idea of its practical application.

In the earliest period of the history of voltaic electricity, indeed, we find that M. Cruickshanks had observed that metals were "revived" from their solutions at the negative pole of the battery; and in 1805 M. Brugnotelli stated that he had "gilt in a complete manner two large silver medals, by bringing them, by means of a steel wire, into communication with the negative pole of a voltaic pile, and keeping them immersed in ammoniuret of gold, newly made and well saturated." It was not, however, till 1839 that any practical application was made of the deposition of metals from their solutions. There are three competitors for the honour of the priority of invention; but each one has the merit of having originated it about the same time independently of the others. M. Jacobi of St. Petersburgh asserts that he made the application of the process in February 1837; but the first notice of his experiments made known in this country was published in the *Athenæum* of May 4, 1839. In 1837, Mr. Spencer of Liverpool had obtained a counterpart of the head and letters reversed of a penny-piece, which he had fortuitously used as a conducting-plate in his battery; and on the week following the publication of the notice of M. Jacobi's experiments, Mr. Spencer gave notice that he should read a paper at the Liverpool Polytechnic Institution, containing the results of his experiments on the same subject; but the reading of it was deferred till September. In the mean time, a letter in the *Mechanics' Magazine*, from Mr. Jordan, a printer, gave a full and accurate description of the process. It, however, attracted no attention; and the matter dropped until Mr. Spencer's paper was read in Liverpool, illustrated with various specimens of electrotypes.

The first efforts with the electrotype process in this country were limited to obtaining fac-similes of coins and medals. It was endeavoured to be carried out on the Continent on a large scale, by applying it to the manufacture of all kinds of copper vessels; but we believe the operation was found more costly than the ordinary mode of fabrication.

Electro-chemical metallic deposits have been successfully applied to coating natural objects with a film of metal, to the transference and multiplication of elaborately-engraved plates, and even the delicate pictures of the Daguerreotype have been solidified by this means. But the most extensively-useful application of the process has been to silver-plating and to gilding. Electro-plating has been carried to a high state of perfection, and in many respects it possesses considerable advantages over the old modes of operating. Electro-metallurgy is yet, however, in its infancy;

and though the experiment of fabricating metallic vessels by means of electro-chemical deposition has hitherto failed as a commercial undertaking, it is not improbable that further improvements—especially the discovery of some cheaper means of exciting electricity for practical purposes—may eventually render it an important branch of manufacturing industry.

A new and very unexpected source of electricity was discovered in 1840 in effluent high-pressure steam. The discovery arose accidentally, owing to the issue of steam from a fissure in the boiler of a steam-engine at Seghill, near Newcastle. The engineer happened to have one hand in the issuing steam, whilst he touched the lever of the valve with the other, and was surprised to see a bright spark, accompanied by an electric shock. The same effect was produced whatever part of the boiler he touched, provided one hand was in the effluent steam.

Mr. Armstrong, to whom the fact was communicated, instituted several experiments with a view to develop the phenomena and ascertain their cause. He obtained sparks four inches in length from the issuing steam, by holding in it a bundle of wires, insulated by a glass rod, or held by a person standing on a glass stool. When the boiler was insulated, the electrical effects were increased, and it was found that more electricity could be drawn from the boiler itself when thus situated, with the steam issuing from it, than was collected by holding a conducting body in the steam. The electricity of the boiler was generally found to be negative, and that of the steam positive.

One of the extraordinary features of this discovery was the great quantity of electricity evolved. Mr. Armstrong in his experiments with a locomotive boiler produced effects upwards of seven times greater than those from a plate-machine three feet in diameter, working at the rate of seventy revolutions in a minute; and the apparatus at the Polytechnic Institution, which was constructed purposely for the evolution of electricity from high-pressure steam, produces much more powerful effects.

The cause of the development of electricity by this means was at first considered to be owing to the capacity of steam for the electric fluid being much greater when in its expanded state than when compressed within the boiler; and the phenomenon of the excitement of so large an amount of electricity by change of state was thought to afford a satisfactory illustration of the generation of atmospheric electricity. This explanation was so simple, and appeared so completely in accordance with the Franklinian theory of electrical excitement, that it seemed to command belief; and we must admit it was with considerable reluctance we felt compelled to abandon it. Professor Faraday undertook to investigate the question; and by a long series of well-devised and carefully-conducted experiments, he appears to have proved very conclusively, that in the evolution of electricity the steam acts only a secondary part; and that the immediate cause of the electrical excitement is the friction of particles of water against the sides of the jet whence the steam issues. In pursuing the experiments with compressed air and gases, as substitutes for steam, the same results were obtained when the tubes and jets contained moisture; but no electricity was apparent when the air and gases were dry.

An apparatus on a small scale for experimenting on the electricity

evolved by effluent steam is one of the wants of the laboratory; and without such means of investigation, the subject has not received so much attention as it deserves. The great amount of electricity, of high intensity, that can be thus excited, might probably by some more convenient arrangement be rendered practically useful.

Since the discovery of the evolution of electricity during the emission of high-pressure steam, there has been no marked advance in electric science. The last ten years have, however, been distinguished for numerous ingenious applications of electric force, which has been made to subserve almost all kinds of purposes, from the transmission of thought to the performance on musical instruments.

We have endeavoured in the preceding sketch to note and render intelligible those successive stages of discovery and of inductive investigations which have given to electricity, though comparatively a science of recent date, a rank as high, and a character as important and interesting, as that of any other of the physical sciences. Though so much has been done in developing and in practically applying electrical phenomena, much more remains to be accomplished: the field is yet only partially cultivated. A large tract remains unexplored, in which we anticipate succeeding cultivators will bring to light additional facts as extraordinary as any hitherto discovered. Their labours may remove the veil that at present obscures the nature of the connexion between frictional electricity, voltaism, heat, and the magnetic force; and may elucidate the mysterious influence which electricity is known to exercise on the functions of vitality.

PART II.

THE PHENOMENA OF ELECTRICITY.

CHAPTER V.

GENERAL PROPERTIES.

Static and current Electricity—Electrical excitement by friction—Attraction and repulsion—Illustrative experiments—Electrics and conductors—All substances electrics when insulated—The opposite kinds of Electricity—Negative and positive electrics changeable—Mutual dependence of the two Electricities—Electrical induction—The Electrophorus—Influence of conductors on surrounding bodies—The Electrometer—Various inductive powers of electrics—Explanation of all electrical phenomena by induction—The two theories of Electricity.

In the foregoing outline of the history of electricity we have traced the progress of the science from the first feeble spark to its identification with the lightning's flash; and thence—pursuing its course into the vast field which the excitement of electric force by chemical action has opened—we have endeavoured to follow its rapid strides since Galvani convulsed the limb of a frog, Volta constructed his wonder-working pile, Davy decomposed the alkalies and earths, and Œrsted detected magnetism in the electric current, till Faraday, reversing the process, has from magnetism eliminated electric fire.

We have now to describe more particularly the great variety of electrical phenomena, and the means by which they are produced in the present advanced state of the science. In doing this we shall proceed nearly in the same order in which the leading facts presented themselves in our historical sketch; commencing, in the first place, with the phenomena of frictional, or as it is more frequently called "static electricity." The latter term is applied to distinguish the action of the force excited by friction from that of the voltaic battery; frictional electricity exhibiting itself in a state of equilibrium, and remaining comparatively at rest, excepting during the instant of discharge; whilst voltaic electricity appears to be constantly in motion from one pole of the battery to the other, and has hence been called current electricity.

The friction of a glass rod or stick of sealing-wax, adopted by the early electricians as their only means of exciting electricity, affords the simplest mode of exhibiting the phenomenon of electrical excitement. A glass tube about two inches in diameter and two feet long answers the purpose

very well. It should be made perfectly dry, and then corked at each end; and if varnished inside, to prevent the condensation of moisture on the glass, it will be better. A piece of black silk, on which some of the amalgam of mercury, zinc, and tin, has been spread, forms the best rubber. On rubbing the tube briskly with the silk, after both have been first warmed, electricity will be excited in almost all states of the atmosphere; and when the weather is fine and frosty, loud cracklings will be heard. In the dark, flashes of light will be observed darting from the tube to the hand that holds it; and on presenting the knuckle within an inch or two of the excited glass, sparks will be emitted, accompanied by a slight tingling sensation.

When a downy feather is held at some distance from the excited tube, the fibres will be attracted towards it, and when liberated, the feather will rush to the glass. In a short time, however, the downy parts will be observed to separate from each other, and when the feather is charged with electricity, it will fly off nearly as rapidly as it was attracted. The feather, when thus repelled from the tube, will not again approach until it has parted with its charge of electricity; and to enable it to do so, it will rush towards the hand or towards the nearest conducting body. If, however, before the feather has had the opportunity of parting with the charge, the excited tube is brought near, it is repelled farther off, and it may in this manner be chased round the room, and kept suspended in the air.

The feather, when in a charged state, exerts an attractive force on all surrounding bodies equal to that with which it is attracted towards them; and if a light conducting body were suspended near, they would rush towards each other with equal forces, and with velocities inversely proportioned to their respective weights. The same law also regulates the repelling force; and when two light bodies charged with electricity from the glass tube are suspended near to each other, they will be mutually repelled. If two small pieces of cork, for example, or what is still better, two pith balls, are suspended by strings of equal length so as to touch, and they are then charged with electricity from the glass tube, they repel each other and keep apart until they are either touched by a conducting body, or the electricity is gradually discharged into the air.

The properties of electric attraction and repulsion may be illustrated in a great variety of ways, some of which are extremely amusing. If a number of small figures are cut out in paper, or carved out of pith, and an excited glass rod be held a few inches above them on the table, the figures will immediately commence dancing up and down, assuming a variety of droll positions. A favourite posture, if we may so express it, of these little figures, is that of standing on the head or on one hand, presenting a foot towards the glass, their little frames being agitated all the time with a quivering motion. From this position of the figures may be learned the fact that first suggested to Franklin the means of drawing lightning from the clouds. The sharp edges and corners of the paper serve as points to draw off the electricity from the excited glass tube, and each one of the figures in that posture is operating, on a small scale, in the same manner as the lightning-conductor on a church-steeple when a thunder-cloud is passing over it. This action of the edges and points of the paper in drawing off the electricity at a distance, prevents the figures cut out in paper from dancing so energetically as those made of pith, and pith balls act more

briskly than either. The experiment can be shewn better by means of an electrical machine than with the excited tube, by suspending horizontally from the prime conductor a metal disc a few inches above a flat metal surface connected with the earth, on which the figures are placed. By this arrangement the dancers have more space for their lateral gyrations, and sometimes waltz together very laughably.

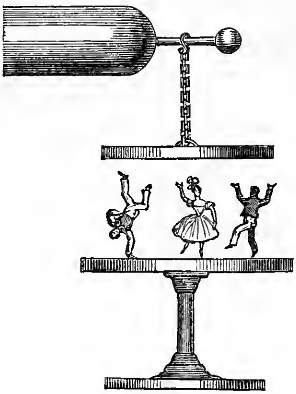


fig. 1.

Experiments illustrative of electric attraction and repulsion may be greatly diversified when an electrical machine is used, so as to increase the quantity of electricity and to conveniently apply it. Among the apparatus commonly employed for exhibiting this property in an amusing manner is a doll's head with long hair. When attached to the prime conductor of the machine, the hairs stand erect, presenting an exaggerated representation of fright.


fig. 2.

A dry glass tumbler becomes charged by grasping it with the hand and presenting the inside to a point fixed on the conductor. If it be then placed over a number of pith balls on the table, the balls dance up and down with great rapidity, each ball being first attracted to the top or to the sides of the glass, and when charged is repelled or falls on to the table, where it discharges the electricity it has received, and is again attracted to the glass. In this manner the tumbler is gradually discharged of its electricity. The outside of the glass is equally charged with the inside, though negatively, and parts with its electricity to the air or surrounding bodies in proportion to the discharge of the interior surface; it being one of the laws of statical electricity, that one surface of a non-conducting body cannot be charged without the other, as will be explained more fully when we come to the consideration of the phenomena of electric induction and the Leyden jar.

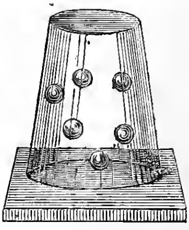


fig. 3.

The bell apparatus, for ringing bells by means of electric attraction and repulsion, is a good illustration of those forces. A metal rod, fig. 4, fixed horizontally to the prime conductor of the machine, serves to suspend three or more small bells. When three bells are employed, the two end ones are hung by wires or chains, and the central one is suspended by a silk thread to insulate it from the conductor, though a metallic communication is made from it to the table by a chain. Two small metal clappers are also suspended by insulating silk threads from the horizontal rod. When the machine is put in action, the bells at each end of the rod being

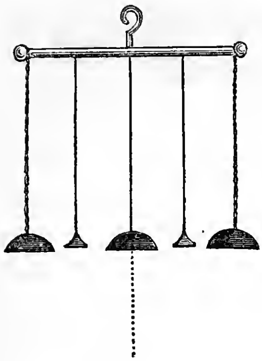


fig. 4.

connected with the conductor by metal connections, become charged with electricity, and attract the clappers, which being instantaneously charged are as quickly repelled and attracted to the central bell, connected with the table, at which their electricity is discharged. The clappers are then again attracted and strike against the other bells, and by these brisk alternate attractions and repulsions keep ringing as long as the machine is in action. It was by attaching a set of bells of this kind to his lightning-conductor, that Dr. Franklin received notice, by their ringing, whenever a thunder-cloud was passing over the apparatus.

One of the effects of electrical attraction is exemplified in its action on running fluids, causing them to flow more quickly. Let a metallic cup, for example, fig. 5, containing water, and with a small opening at the bottom, be suspended from the prime conductor of an electrical machine. If the aperture be so small as to allow the water only to issue by drops when the machine is not in action, the flow will be increased to a stream as soon as the electricity is excited. The water being charged with positive electricity, it is attracted with increased force towards the earth, and that force, added to the attraction of gravitation, produces the more rapid flow.

fig. 5.

The early electricians appear to have had no knowledge of variations in degree of conducting power, nor of electrical excitement, in different substances; but more recent investigations have shewn that conductors and electrics are blended together by such inappreciable degrees, that it is impossible to say to which class some of the intermediate bodies belong. As all substances probably are capable of electrical excitement, they might consequently be all classed in the list of electrics, gutta-percha being at the head, and gold or copper at the bottom. On the other hand, as all substances conduct electricity in various degrees, they might all come within the class of conductors, in which case the order would be reversed. So different, indeed, is the conducting power of bodies usually considered as conductors of electricity, that water, which is classed as a conductor, offers three million times more resistance to the electric fluid than copper.

It is a remarkable fact in the conduction of electricity, that imperfect conductors can compensate by quantity for their deficiency in quality. Thus assuming that in equal bodies of copper and water the latter would not conduct more than the three-millionth part of the quantity of electricity in the same time that would pass by the copper, yet by increasing the quantity of water in a proportionate degree, the resistance in both cases would be equal. We shall have occasion to shew, indeed, in speaking of electric telegraphs, that when the conducting power of water is brought to operate on an extensive scale, the resistance it offers to the passage of electricity diminishes to an inappreciable quantity.

The principal conductors of electricity, arranged in the order of their

conducting powers, is subjoined. It is difficult, however, to determine how far such a list should extend, since all substances conduct in a greater or less degree.

Copper.	Platinum.	Animal fluids.
Gold.	Charcoal.	Sea water.
Silver.	Plumbago.	Fresh water.
Mercury.	Strong acids.	Ice and snow above zero.
Iron.	Soot.	Vapour.
Tin.	Metallic ores.	Rarefied air.
Lead.	Diluted acids.	
Zinc.	Saline solutions.	

We have previously noticed that the best electrics are the worst conductors of electricity, and that all substances may be considered to be electrics or non-electrics in proportion to the resistance they offer to the conduction of electricity. As gutta-percha offers more resistance to the passage of electricity than any other body, it may consequently be considered the best electric; and copper, being the best conductor, should be the farthest removed from the condition of electrical excitement. A copper rod may, however, be converted into an electric by insulation; but when a metal rod is excited by friction, the electricity is discharged at once, when a conducting body is brought near, instead of parting with the electricity by slow degrees, like an excited tube of glass. It seems probable that electricity is always excited by friction under every circumstance, though it is only observable in those substances that have the power of retaining it on their surfaces after being excited. The mere movement of the feet along the carpet is sufficient to excite electricity; as may be shewn by placing the hand on a delicate electrometer whilst the feet are in motion.

The experiment which led Du Fay to the discovery that there are two kinds or states of electricity may be easily repeated. Having caused a feather to be repelled from an excited glass tube, excite a stick of sealing-wax, or what is better, a rod of gutta-percha, and the feather which has been repelled by the glass will be attracted by the gutta-percha. Then holding the glass tube in one hand and the gutta-percha in the other, the feather will be alternately attracted and repelled, and with greater force than when a conducting body connected with the earth is brought near to either of the excited electrics and the feather. After a succession of attractions and repulsions, the electricity of the excited glass and gutta-percha is discharged, the feather having acted as a discharger from one to the other. This experiment clearly shews that the electricity excited in glass, whilst it apparently repels bodies similarly electrified, attracts those that are electrified by wax or gutta-percha. The phenomenon of mutual attraction is shewn more briskly if a piece of gold-leaf or suspended pith ball be substituted for the feather; for the downy fibres of the latter tend to dissipate the electricity quietly from their distended points, and thus prevent the feather from becoming fully charged.

A still more satisfactory way of exhibiting the different actions of the two kinds of electricity is to suspend two pith balls by threads of equal lengths from an insulated metal conductor, as represented in fig. 6; C C being the pith balls suspended from one end of the horizontal metal cylinder A, and insulated from the earth by the glass leg B, fixed into a

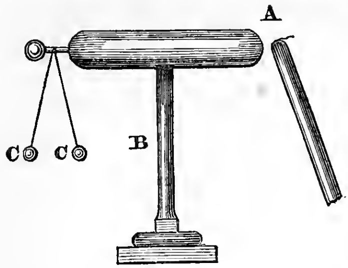


fig. 6.

wooden base. Touch the end A with an excited glass tube, and the pith balls will separate and will continue apart when the tube is removed, each one being electrified with the electricity of the glass. If an excited stick of sealing-wax be then brought near, the expanded balls will collapse, even before the wax touches A. On removing the excited wax without touching the horizontal rod, the pith balls will again separate, and will be in the same electrical condition as before. But if the excited stick of wax come in contact with the rod, or approach it so near as to transmit a spark, the state of electricity becomes changed, and the balls will then expand with the opposite kind of electricity. When the excited wax is again brought near, the pith balls will expand more widely instead of collapsing, as before, and the excited glass tube, which previously made the balls expand, will now cause them to collapse.

It appears, therefore, that the electricity communicated to the balls by the excited glass differs essentially in its attractive properties from that communicated by the excited wax; and Du Fay, who first discovered the difference, distinguished the opposite states of electricity by the terms *vitreous* and *resinous*. These terms are still retained by those electricians who conceive that there are two electric fluids; but those who, with Franklin, entertain the opinion that the different attractive actions are occasioned by the *plus* or *minus* state of the same electric fluid, call the electricity excited by glass *positive*, and that excited by resin *negative*.

Shortly after the discovery of the difference of the two electrical conditions, all the known electrics were classed according to the kind of electricity each one excited; but such classification was afterwards found to be very fallacious, for the state of electricity depends, with few exceptions, on the rubber employed. Even glass and resin, which are considered the types of the two distinct classes of electrics, may be made to interchange their states of electrical excitement; for glass when rubbed with the fur of a cat yields negative electricity, and resin becomes positively electrified when rubbed with metals. The fur of a cat is the only known substance that does not alter its electrical state with whatever it is excited. In the following list of electrics, those which come first excite positive electricity when rubbed with any of those that follow, and are negative when rubbed with those that precede.

Fur of a cat.	Feathers.	Silk.
Polished glass.	Wood.	Gum lac.
Woollen cloth.	Paper.	Rough glass.

The change of electrical excitement seems to depend more on the nature of the surface than on the inherent quality of the electric; for in the preceding list it will be observed that glass is positive when polished, and is strongly negative when roughened. The following table, given by Cavallo as the results of experiments, shews more fully the changes effected by different rubbers. It will be observed, however, that the relative elec-

trical conditions do not exactly agree with those mentioned in the foregoing list.

Substances excited.	Kind of electricity.	The rubbers.
Back of a cat	Positive	Every substance tried.
Polished glass	Positive	Every substance but the back of a cat.
Rough glass	Positive	Dry oiled silk, sulphur, metals.
	Negative	Woollen cloth, paper, wax, the human hand.
Tourmalin	Positive	Amber, a current of air.
	Negative	Diamond, the human hand.
Hare-skin	Positive	Metals, silk, leather, hand.
	Negative	Finer furs than hare-skin.
White silk	Positive	Black silk, metals.
	Negative	Paper, hand, hair.
Black silk	Positive	Sealing-wax.
	Negative	Furs, metals, hand.
Sealing-wax	Positive	Metals.
	Negative	Furs, hand, leather, cloth.
Baked wood	Positive	Silk.
	Negative	Flannel.

These facts respecting the change of electrical state from positive to negative are difficult to explain on any known hypothesis. If we adopt the theory of Franklin, and infer that the positively electrified bodies only are the exciters of electricity, then we must assume, in those cases where a change in the kind of electricity is produced by a change of rubber, that the body on which positive electricity is excited is always to be regarded as the electric. Thus when glass which has been positively excited by friction with silk becomes negative by friction with the fur of a cat, it must in the latter case be regarded not as the electric, but as the rubber. The frequent change of state from positive to negative, which we shall have further occasion to notice, presents, indeed, one of those mysteries of electric science of which no satisfactory explanation has hitherto been afforded.

One of the remarkable features of the two electricities is their dependence on each other. Positive electricity cannot be excited without the excitement at the same time of an equal amount of negative electricity, nor can the latter be excited without the evolution of positive electricity. Thus, when a tube of glass held in the hand is rubbed with silk, the hand holding the silk has a quantity of negative electricity communicated to it equal to the positive electricity excited in the glass. In ordinary circumstances the negative electricity is not apparent, because it is conducted to the earth as quickly as it is evolved; but when the person who is exciting the glass tube is insulated from the ground, sparks of negative electricity may be taken from any part of his body. Not only is it impossible to excite positive or negative electricity without at the same instant exciting electricity of the opposite kind, but the presence of an excited electric induces in bodies at a distance from it the opposite electrical state. When an excited glass tube is placed at the distance

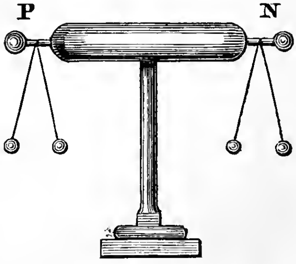


fig. 7.

of a foot from the end P of the horizontal insulated metal cylinder N P, furnished with pith balls at each end, the balls will be immediately distended by the influence of the excited tube, though no electricity is communicated to them directly from the glass. On the removal of the tube to a greater distance, the balls will collapse, and no trace of electricity can be detected in the rod. But if the finger or any other conducting body touch the end N whilst the balls are distended under the influence of the glass tube near P, and it is withdrawn whilst the influence is exerted, then on removing the tube the balls will remain distended, the rod having received a charge of negative electricity. The electrical state of the rod may be easily tested by bringing the glass tube near it again, when the balls will be seen to collapse on its approach, instead of expanding as at first.

Having touched the rod to remove the electricity, again bring the excited glass tube near the end P, and whilst the balls are distended under its influence, let an excited stick of sealing-wax be brought near the same end, and the balls will partially collapse; but if the excited wax approach towards the other end, they will be separated still farther apart.

In this experiment the approach of the positively excited glass tube towards the insulated rod repels the electricity to the end farthest from the excited tube. The equilibrium of the natural electricity in the rod is thus disturbed, and it exhibits electrical phenomena without in fact having received any charge of electricity. According to the theory of Franklin, the rod has parted with a portion of its natural electricity, which was repelled to one end by the excited glass, and it is left in a *minus* state until it regains its natural quantity from surrounding bodies.

These simple experiments afford most satisfactory illustrations of the important property of *induction;* and they should be, therefore, carefully studied in all their bearings. The fact has been satisfactorily established, that every excited electric induces electricity of an opposite kind in all surrounding bodies; and that this influence is exerted through the air or any other non-conducting substance with instantaneous rapidity. There is no actual communication of electricity in these cases, but an attractive or repelling action is exerted only so long as the influence of the electric operates. The instantaneous transmission of this inductive force through bodies that offer the most resistance to the conduction of the electric fluid, bears some analogy to the transmission of radiant heat instantaneously through the non-conducting air. How far the influence extends has not been ascertained, but it most probably obeys the same laws as heat and all other radiant forces; extending indefinitely into space, but diminishing in quantity inversely as the squares of the distance.

The property of induction is admirably illustrated in a very ingenious and useful apparatus invented by Volta, called the Electrophorus. It consists of a thick flat cake of resinous substance laid upon a sheet of metal. The resinous cake being rubbed with hot flannel, the upper surface becomes charged with negative electricity, which induces an equal positive charge on the under surface in contact with the metal plate. A metal disc insulated by a glass handle is then pressed upon the excited resin. As the electricity cannot pass away through the insulating glass handle, the effect of the application of the metal disc on to the excited resin is to induce electricity on the surfaces of the metal, each surface

being in an opposite state; the positive electricity being attracted to the surface nearest the resinous electric, and the negative being repelled to the upper surface. If the disc be pressed upon the resin, and removed without any connexion with the earth, the equilibrium of its two surfaces will be restored as soon as it is lifted from the influence of the electric, and it will exhibit scarcely any sign of having gained electricity by the contact. But if whilst resting on the excited resin, the upper surface be touched, the negative electricity is thereby withdrawn; and when the disc is lifted away, it remains positively charged, and a strong spark may be taken from it. This operation may be repeated any number of times, for none of the electricity of the excited resin is communicated directly to the disc, which becomes electrical merely by the induction of opposite kinds of electricity on its two surfaces; the equilibrium of its natural state being disturbed by the attractive force of the excited electric. When a plate of glass is substituted for one of resin, the electricity of the disc of course becomes reversed. The upper surface is then positive whilst under the influence of induction, and on allowing that to escape by communication with the earth, the metal when removed from contact is in the negative state.

The continued supply of electricity from an electrophorus by a single excitement of the resinous plate renders this instrument occasionally very useful in electrical experiments, where a small quantity of electricity only is required, as it is sufficiently powerful to charge a good-sized Leyden jar. Figure 8 represents the apparatus as generally constructed. The cake of resinous matter, A A, is poured on a circular wooden pan, lined with tin-foil; C is the metal disc, usually made of brass, rounded at the edges; and B is the glass handle for the purpose of insulation. A sheet of gutta-percha might be advantageously substituted for the resin, and a handle of baked wood varnished would serve nearly as well as glass.

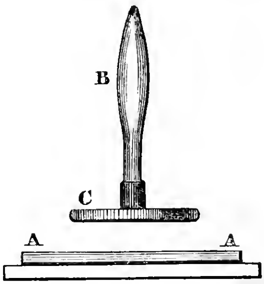


fig. 8.

The induction of electricity through glass may be shewn by exciting one side of a thin plate when laid flat on the table. The glass when rubbed with silk becomes positively electrified on its upper surface, and the under surface is at the same time charged with negative electricity. This may be shewn by lifting the glass by the corners and bringing it near the pith balls (fig. 6), after they have been distended by contact with an excited glass tube. It will then be seen that the balls will be distended farther when the upper surface of the pane of glass is presented to them, and that they will collapse on the presentation of the under surface.

It has been already stated, that in every case of electrical excitement electricity is induced in all surrounding bodies. When an excited glass rod, for instance, is held in the middle of the room, the walls and every thing they enclose are under its influence, though it may be too feeble to be appreciated. The effect of the excited glass is to attract a certain portion of negative electricity towards it, and a mutual attractive force is exerted between the excited glass and every object thus influenced. Many persons are painfully sensitive of the approach of a thunder-storm,

and often complain that there is "thunder in the air," when no storm succeeds. There can be no doubt that during the passing of a thunder-cloud electricity is induced in all bodies beneath; and Faraday on this account considers it dangerous to have iron roofs to powder-magazines. Such a roof might have electricity induced in it by the action of the electricity in the cloud, and a spark might pass from the under surface of the roof to the ground.

The action of that useful instrument, the electrometer, depends for the most part on the induction of electricity. The simplest indicator of electrical excitement is the arrangement of two pith balls, already shewn in fig. 6. The weight of the balls, however, and the imperfect conducting character of the suspending string, prevent it from being very sensitive. Bennett's gold-leaf electrometer is a much more delicate instrument. It consists of a wide glass tube, about four inches long, mounted on a metal stand, and covered with a metallic cap. From the inside of the cap there is a small projection, to which two thin strips of gold-leaf are attached. The extreme lightness of the gold-leaf and its great conducting power render it extremely sensitive to the action of small quantities of electricity; and the delicacy of the instrument is increased by fixing strips of tin-foil on the sides of the tube, opposite to the gold leaves, which are attracted towards them and diverge with very slight electrical excitement.

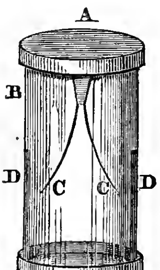


fig. 9.

Fig. 9 represents the form of this useful indicator of the presence of electricity. The brass cap A fits closely on to the tube B, and from the cap the gold-leaves C C are suspended. Two strips of tin-foil, D D, are connected with the metallic base, and through it with the earth.

To increase the sensibility of this electrometer, metal discs, A B, called condensers, are added, one of which is attached to the brass cap, and the other is mounted on a support that is movable by a joint at the bottom, so that it may be removed to the position indicated by the dotted lines in the figure. By the induction of electricity on the surface of the movable disc several successive times, and by its reaction on the electrometer, an accumulation of the electric force is effected; by which means the presence of otherwise inappreciably small quantities of electricity is detected.

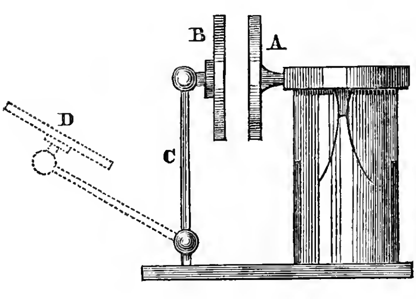


fig. 10.

This instrument, and others of a similar construction, though called *electrometers*, do not indicate the quantity of electricity; and the name *electroscope*, which has been recently applied to them, is more appropriate to their character.

The torsion-balance of Coulomb, which has been previously noticed, measures the electric force exerted, and may therefore with strict pro-

priety be called an electrometer. It consists of a fine rod of shellac, *c*, at each end of which there is a gilded pith ball, the rod and balls being suspended from the centre by a filament of spun-glass *a*. The ball *d* is similar to the others, and is also fixed to a rod of shellac, with a corresponding ball at the other end. The latter is called the carrier-ball, as it conveys electricity from the body to be tested to the electrometer. When applied to the excited body under examination, it receives a portion of the electricity, and on being then placed in its position in the instrument, the suspended ball that rests against it is repelled. By turning the screw *b* the two balls may be brought together; and the amount of torsion or twist given to the filament of glass, so as to overcome the electrical repulsion, is measured by a graduated scale.

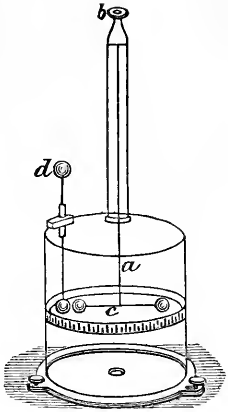


fig. 11.

The action of electrical induction takes place through all non-conducting bodies, though not with equal facility, the transmission of the influence being readiest through those substances which are the worst conductors of electricity. The term *dielectrics* has been given to those bodies that permit induction to take place through them; but it seems to be a useless multiplication of names, since all electrics are also dielectrics. The following has been ascertained experimentally to be the comparative order of the inductive power of the principal electrics:

SPECIFIC INDUCTIVE CAPACITY.

Air	1·00	Glass	1·90
Resin	1·77	Sulphur	1·93
Pitch	1·80	Shellac	1·95
Wax	1·86		

Though gutta-percha is not included, its inductive capacity is known to be greater than that of any other body.

An important portion of Faraday's *Experimental Researches in Electricity* is occupied with investigations respecting the nature of inductive action. He has arrived at the conclusion that induction "is a physical action occurring between contiguous particles, never taking place at a distance without polarising the molecules of the intervening dielectric, causing them to assume a peculiar constrained position, which they retain so long as they are under the coercing influence of the inductive body." According to this view of the question, therefore, all the particles of air, and of every solid non-conductor, must assume a polar arrangement, like the particles of iron-filings when within the sphere of magnetic attraction; and in this manner act directly, through a chain of contiguous particles, on the bodies in which electricity is induced.

The property of induction is now adduced to explain every phenomenon of static electricity; irrespective of the opposing theories of the two electricities, or of the mode by which inductive action is effected. The phenomena of attraction and repulsion are thus explained: the two states of electricity being admitted to exert a mutual attraction on each other, the induction of negative electricity by positive, and the reverse,

must necessarily be attributable to an attractive force. The repulsion of bodies similarly electrified is considered to be caused by attractive forces in opposite directions, and not by any operating repulsive power exerted among the particles of such bodies. Two similarly electrified pith balls, for example, are supposed to diverge in consequence of each one inducing an opposite state of electricity in surrounding bodies, towards which they are consequently attracted in opposite directions; the divergence and apparent repulsion from each other being occasioned altogether by attractive forces. The existence of a negative force, as repulsion may be regarded, is indeed opposed to the principles which have been established by investigation in other departments of physical science; and by the hypothesis of inductive action the student of electricity is called upon to dismiss the action of repulsion from operating forces, as the student of chemistry is compelled to deny the existence of cold as a positive property. It seems questionable, however, whether the term "induction" has not been introduced unnecessarily, since all the phenomena may be regarded as the results of electrical attraction.

The question whether there are two distinct kinds of electricity, or only one kind which is exhibited in different states of intensity, though interesting in a theoretical point of view, is not essential to the explanation of electrical phenomena, which may be almost as readily explained by one hypothesis as by the other. The analogy of those other powers in nature which, though apparently operating as distinct forces, have been proved to consist of only one, as well as the more simple character of the *plus* and *minus* theory, incline us strongly in its favour.

The foundation on which the Franklinian theory rests is thus stated by Dr. Priestley: "According to this theory, all the operations of electricity depend upon one fluid *sui generis*, extremely subtle and elastic, dispersed through the pores of all bodies; by which the particles of it are strongly attracted, as they are repelled by one another. When the equilibrium of this fluid in any body is not disturbed,—that is, when there is in any body neither more nor less of it than its natural share, or than that quantity which it is capable of retaining by its own attraction,—it does not discover itself to our senses by any effect. The action of the rubber upon an electric disturbs this equilibrium, occasioning a deficiency of the fluid in one place and a redundancy of it in another. This equilibrium being forcibly disturbed, the mutual repulsion of the particles of the fluid is necessarily exerted to restore it. If two bodies be both of them overcharged, the electric atmospheres repel each other, and both the bodies recede from one another to places where the fluid is less dense. If both bodies be exhausted of their natural share of this fluid, they are both attracted by the denser fluid existing either in the atmosphere contiguous to them, or in other neighbouring bodies; which occasions them still to recede from one another as much as when they were overcharged."*

The statement of the theory of vitreous and resinous electricity we shall also take from Dr. Priestley, who, though an advocate for the single-fluid hypothesis, has stated the arguments for and against both with great impartiality:

* Priestley's History of Electricity.

"Let us suppose, then, that there are two electric fluids which have a strong chemical affinity with each other, at the same time that the particles of each are as strongly repulsive of one another. Let us suppose these two fluids in some measure equally attracted by all bodies, and existing in intimate union in their pores; and while they continue in this union, to exhibit no mark of their existence. Let us suppose that the friction of any electric produces a separation of these two fluids, causing the vitreous electricity of the rubber to be conveyed to the conductor, and the resinous electricity of the conductor to be conveyed to the rubber. The rubber will then have a double share of the resinous electricity, and the conductor a double share of the vitreous; so that upon this hypothesis no substance whatever can have a greater or less quantity of electric fluid at different times. The quality of it only can be changed. The two electric fluids being thus separated will begin to shew their respective powers, and their eagerness to rush into reunion with one another. With whichsoever of these fluids a number of bodies are charged, they will repel one another, and they will be attracted by all bodies which have a less share of that particular fluid with which they are loaded; but will be much more strongly attracted by bodies which are wholly destitute of it, and loaded with the other. In this case they will rush together with great violence.

"Upon this theory every electric spark consists of both fluids rushing contrary ways and making a double current. When, for instance, I present my finger to a conductor loaded with vitreous electricity, I discharge a part of the vitreous and return as much of the resinous, which is supplied to my body from the earth. Thus both the bodies are unelectrified, the balance of the two powers being perfectly restored."

Dr. Priestley proceeds to state, with great fairness, the analogies and the facts which may be adduced in support of the two distinct electric fluids. The combination of two caustic and powerfully-active substances, as an alkali and an acid, in the form of a neutral salt, in which the properties of neither of the constituent parts is perceptible, is one of the analogies advanced in favour of the vitreous and resinous fluids being combined, and rendered perceptible only when their combination is disturbed.

It appears from the preceding consideration of the properties of the two electricities, that the cause of electrical attraction is the endeavour they make to combine and return to a neutral state. This attractive power, which is extended in the phenomena of induction to considerable distances, seems to afford sufficient explanation of the cause of those phenomena, without supposing the exertion of any separate action of inductive force. And if we concur in the explanation assigned for the mutual repulsion of negatively-electrified bodies, attractions of the two electricities in opposite directions will supply adequate cause for all the phenomena of repulsion, without the necessity of supposing that there exists any positively active repulsive power in electricities of the same kind.

CHAPTER VI.

DIRECT DEVELOPMENT OF ELECTRICITY.

Electrical machines; Cylinder, Plate, and Gutta Percha—Influence of points—Explanation of the cause—Electricity confined to surfaces—Intensity of machine-excited electricity—Inflammation of combustibles by the spark—Resistance of the air—Nature of electric discharge—Disruptive, brush, and glow discharge—Colour of the electric spark.

THE excitement of electricity by friction with the hand is adequate to illustrate the primary phenomena and elementary properties of the electric fluid; but for the exhibition of its powerful effects and more complicated actions, it is requisite to employ other apparatus. The quantity excited must be greater in a given time, and means must be provided for collecting and accumulating the electricity when excited.

The electrical machines that were used by Du Fay and Priestley consisted of a sulphur globe whirled round on an axis, with the hand applied for a rubber. The globes of sulphur were supplanted by cylinders of glass; and though that form has in a great measure given place to the more powerful plate-machine, the cylinder is so well suited for purposes of general experiment, that it continues to be preferred in cases where no extraordinary power is required.

Figure 12 represents an approved construction of this kind of electrical

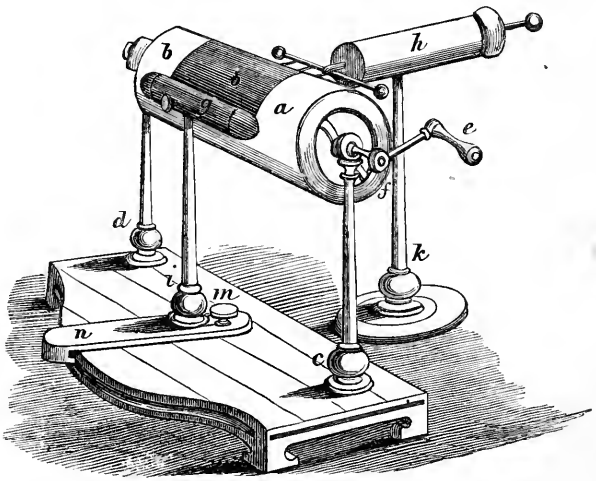


fig. 12.

machine. The cylinder *a*, placed horizontally, is mounted upon supports of glass varnished, to insulate it from the ground. The rubber *g* consists of a hair-cushion covered with leather, over which is placed a flap of black silk. The cushion is mounted on a glass support, for the purpose of insulation when the exhibition of negative electricity is re-

quired; and it is adjusted by a screw *m*, to regulate the pressure on the cylinder. In the ordinary working of the machine the cushion is connected by a chain with the ground, whence the supply of electricity is derived. A hollow brass or tin cylinder *h*, rounded at each end, and placed at a short distance from the glass cylinder, serves to collect the electricity as it is excited. On the side facing the glass there is a row of metal points which facilitate the collection of electricity; and to prevent it from passing off to the earth, the metal cylinder, called the prime conductor, is mounted on a varnished glass support *k*. For the convenience of attaching apparatus to the prime conductor, holes are made on the top and at one end. In some electrical machines a metal cylinder similar to that of the prime conductor is attached to the rubber, as represented in the wood-cut, for the purpose of facilitating experiments with negative electricity. In large cylinder-machines the prime conductor is usually mounted on a separate stand, detached from other parts of the apparatus; but moderately sized instruments are generally constructed with the conductor attached to the same base as the cylinder, an arrangement being contrived to allow of its adjustment at different distances.

A cylinder electrical machine of about nine inches diameter is sufficiently large for ordinary purposes of experiment. An apparatus of that size will, under favourable circumstances, fully charge a quart Leyden jar with twelve turns of the handle.

Little need be said in explanation of the action of this machine, which is only a modification of the means of electrical excitement by the friction of a glass tube with the hand. On turning the handle *e*, friction is produced between the surface of the cylinder and the rubber; the electrical equilibrium is thereby disturbed, and electricity is excited, which, when the prime conductor is removed, exhibits itself in bright flashes of light round the cylinder. When the points of the prime conductor are presented to the revolving cylinder, the electricity is immediately transferred to it, and it emits sparks to any conducting substance brought near. The electricity thus abundantly excited is supplied from the earth to the rubber, which is continually having its supply drawn from it by the coercive force called into action by friction with the glass. That the electricity is derived from that source is evident from the great diminution of quantity when the metallic connexion between the rubber and the ground is removed. In that insulated state the rubber becomes strongly charged with negative electricity, and sparks pass between it and any conducting body brought near almost as abundantly as from the prime conductor when in full action.

The rationale of the excitement of electricity by the machine is, according to the Franklinian theory, very simple. The friction of the glass and silk, by disturbing the electrical equilibrium, deprives the rubber of its natural quantity of electricity, and it is therefore left in a negative state, unless a fresh quantity be continually drawn from the earth to supply its place. The surplus quantity is collected on the prime conductor, which thereby becomes charged with positive electricity. On the hypothesis of two electric fluids, the same frictional action causes the separation of the vitreous from the resinous electricity in the rubber, which therefore remains resinously charged; unless there be a connexion with the earth to restore the proportion of vitreous electricity of which the rubber has been deprived.

The electrical excitement of the machine is greatly increased by applying to the rubber a metallic coating consisting of an amalgam of zinc, tin, and mercury. It is prepared by melting together two parts by weight of zinc, and one of tin, with which, whilst in a melted state, six parts by weight of mercury are mixed. The mass is shaken well together till it cools, and it is then pounded finely in a mortar and mixed with lard to the consistence of a paste. The amalgam is spread on the cushion only, care being taken to prevent it from being spread on the silk flap.

The effect of an amalgam of this kind in increasing the electrical excitement is very decided, though some difference of opinion exists as to the principle on which the action depends. It has been imagined that the amalgamated metals are oxydised during the friction with the rubber, and that the electricity is due to chemical action. The more simple explanation appears to be, that the coating of metal on the rubber assists in conducting the electricity from it. The use of the silk flap is merely to prevent the electricity from discharging itself into the air before it reaches the conductor, and it would be unnecessary if the collecting points were brought near the rubber. The adhesion of particles of amalgam to the silk flap is prejudicial to the action of the machine by forming conducting points for the dispersion of the excited electricity.

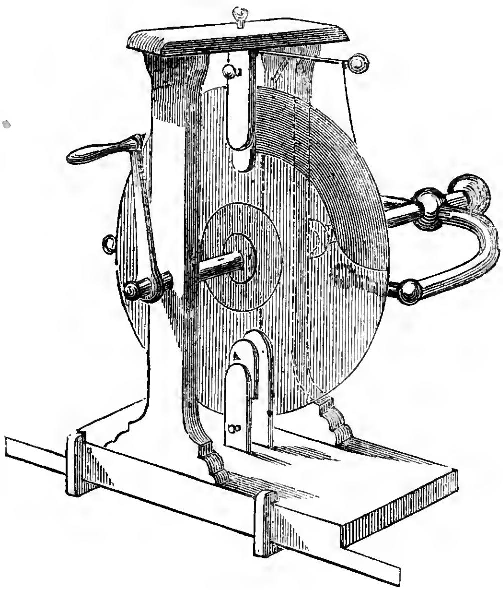


fig. 13.

Plate machines are now much used on account of the greater quantity of electricity that can be excited by that arrangement of the instrument. A disc of glass about a quarter of an inch thick has an axis fixed in its centre, firmly supported by two cheeks of baked wood. On the upper and lower parts of these cheeks four cushions are fixed, to press against

both sides of the glass plate at the top and at the bottom. Small flaps of silk are attached to the cushions to prevent the electricity excited from being dissipated before it arrives at the collecting points of the prime conductor. The conductor itself is also fixed to the upright cheeks, but is insulated from them by a horizontal glass support. Rows of points serve to collect the electricity from both sides of the glass plate, at the top and bottom. By this arrangement a much larger surface of glass is exposed to friction, and two rubbers can be employed on each side of the plate. The surface exposed to friction in a plate machine with a glass disc of only one foot in diameter is more than double that of a nine-inch cylinder machine.

The inconvenience of a plate machine, as usually constructed, arises from the imperfect insulation of the rubbers, in consequence of which the negative electricity excited cannot be exhibited.

An electrical machine in which the exciting surface consisted of gutta-percha was shewn amongst the philosophical instruments at the Great Exhibition. An endless band of gutta-percha A was stretched over rollers B B placed above each other about two feet apart. The rotation of the upper roller communicated a rapid vertical motion to the band of gutta-percha, which was pressed against at the top and bottom by hard hair brushes, C C, that served as rubbers. The electricity was collected on each side by a branching conductor D, armed with points, and concentrated in a similar manner to the arrangement of the plate machine.

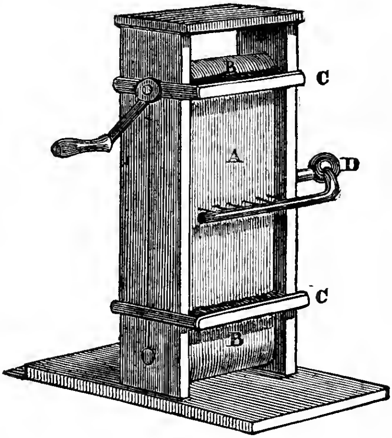


fig. 14.

Though we have not had an opportunity of trying the effect of this machine, we have heard it very favourably spoken of. It presents some practical advantages that would make it preferable to glass machines, among which must be mentioned its non-liability to fracture, and the superior excitability of its surface.* Sheets of gutta-percha may also be attached to discs of wood to serve instead of glass in plate electrical machines.

With an electrical machine of any of the kinds mentioned, most of the phenomena of electricity can be exhibited in a much more convenient manner than by an excited glass tube, and some of them could scarcely be manifested without the aid of such an apparatus. It is requisite, however, for its due action, that the machine should be placed before the fire for a short time before it is used, to expel the moisture that adheres to the glass and the cushion, and that the insulating glass supports should

* The Jurors' Reports of the Great Exhibition, which have been published since the above notice was written, make very favourable mention of this machine.

be rubbed with a warm silk handkerchief. These conditions being attended to, and the rubber being covered with amalgam, the prime conductor will emit sparks several inches in length when the handle is turned rapidly. The action of the apparatus will, however, be considerably influenced by the state of the weather, whatever precautions be taken to keep it dry. On a fine frosty day the sparks emitted will be longer and more abundant than can be obtained when the atmosphere is charged with moisture, because the damp air acts as a conductor in restoring the electrical equilibrium.

The peculiar influence of points in withdrawing the charge from an electrified body may be readily shewn by fixing a pointed wire to the prime conductor of an electrical machine. When the point is attached, the apparatus appears to be deprived of its power of exciting electricity, and but few and very feeble sparks will be emitted. The point, in fact, disperses the electric fluid almost as rapidly as it is excited; and if the room be darkened, rays of light will be seen issuing from it into the air in the form of a cone, of which the point is the apex, the light being brighter there, and diminishing as the rays expand. When the point is fixed to the insulated rubber charged negatively, the effect is the same in the dispersion of the charge, but the appearance is that of a star instead of a luminous cone. These different appearances of the electric light at the rubber and at the prime conductor induced Franklin to infer that the latter emitted electricity, and was consequently in a positive state, and that the rubber was negatively electrified—the *plus* and *minus* hypothesis being assumed.

On presenting the back of the hand to a metal point fixed on the prime conductor, a sensation similar to that of a small blast of air will be perceived; and several kinds of apparatus have been contrived to exhibit the action of the force, whatever it may be, that issues from or is induced towards electrified points. The most simple of these contrivances is the electrical jack, which consists of four light pieces of wire placed crosswise, and balanced horizontally on a pivot in the centre. The ends of these wires are pointed, and are bent in the direction of a tangent to the circle described by the apparatus during its rotation on its axis.

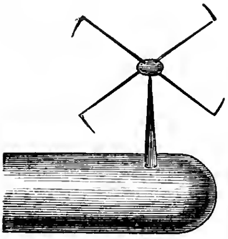


fig. 15.

When attached to the prime conductor, as represented in fig. 15, and the machine is put in action, the blasts from the bent points cause the air against which they strike to react on the apparatus, and to turn it rapidly round; in the same manner that water or steam issuing from jets similarly directed turn water-mills and model steam-engines, on the principle of reaction.

Another and very curious experiment, which is adduced as proving the emission of some active force from an electrified point, is the following: Put a little sealing-wax at the end of the pointed wire A, fig. 16, and whilst the machine is in action melt the wax. A thread of sealing-wax finer than a spider's web will then be propelled from the point; and if a piece of white paper be held near, the convolutions of the web-like films, as they overlap each other, produce a remarkable and sometimes a beautiful effect.

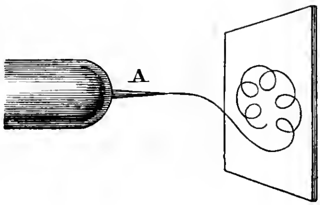


fig. 16.

It might be supposed, if electricity be emitted only from the positive prime conductor, and the insulated rubber be electrified negatively, by having its natural share of electricity abstracted from it, that there would be no emission from the point fixed to the rubber, but rather an influx towards it. This, however, is not the case; for the phenomena of propelling wheels and projecting sealing-wax filaments occur whether the point be positively or negatively electrified. This is one of the difficulties which the advocates of the *plus* and *minus* states of electricity have to contend with; for the phenomena of equal apparent emission from negatively electrified points appears to support the original hypothesis of Du Fay, that there are two distinct electric fluids. To account for the apparent anomaly, it is said that the effect of propulsion is not produced by the emission of negative fluid from the point, but that it is caused by the mutual attractions always subsisting between bodies in opposite states of electricity. The seeming emission of air from points fixed on either of the conductors of the electrical machine is merely a secondary and a mechanical effect produced by the air being put in motion by the continuous discharges from the points.

The cause why points exert such powerful influence in the discharge of electricity has been explained by the researches of M. Coulomb into the distribution of electricity on the surfaces of bodies of different forms. On a sphere, every part of the surface being equally distant from the centre, the distribution of electricity is equal; but the more the shape of the body departs from that of a sphere, the more unequally is the electricity distributed. M. Coulomb insulated a metal rod, two inches in diameter and thirty inches long, with hemispherical ends; and having charged it with electricity, he found that at a distance of two inches from the end the electricity was to that in the middle of the rod as $1\frac{1}{4}$ to 1. At one inch from the end the proportion was as $1\frac{4}{5}$ to 1, and at the extreme end it was as $2\frac{3}{10}$ to 1. It appears from the results of his experiments that the intensity of the electrical charge increases in a very rapid proportion towards the edges of an insulated conductor; that it augments still more at the corners; and that when points project, their extremities concentrate the electricity with great additional intensity.

By the aid of these experiments, the cause of the escape or discharge of electricity from points may be readily inferred. The non-conducting air which surrounds an electrified body resists the escape of the electricity in proportion to its pressure on the surface, the amount of resistance being in an inverse ratio to the intensity of the electric force. If, therefore, the force be concentrated at a point where the amount of surface-resistance to its escape is reduced to the smallest quantity, the concentrated force meets with comparatively little obstruction, and rapidly rushes towards the surrounding bodies which are exerting an attractive power on the excited electricity.

One of the many effects of electrical induction is the distribution of static electricity entirely on the surfaces of conductors. The electricity communicated to any substance induces an opposite state of electrical ex-

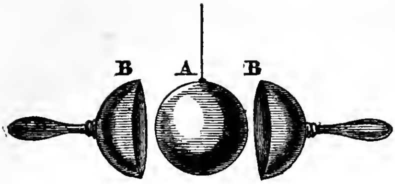


fig. 17.

citement on surrounding bodies, and the mutually attractive influence draws all the electric fluid to the surface. Thus an insulated hollow ball, however thin its substance, will contain a charge of electricity equal to that of a solid ball of the same size, all the charge being distributed, in either case, on the surface alone. An experiment contrived by M. Biot affords a very satisfactory illustration of the distribution of electricity on surfaces.

Let a metal globe A, fig. 17, be suspended by a silken cord, and communicate to it a charge of electricity. Two hemispheres B, B, that will exactly enclose the globe, should be insulated by glass handles, and placed over it when thus charged, so that the exterior surfaces of the hemispheres may become the outside of the globe. Under these circumstances, the whole charge of electricity will be transferred from the globe to the hemispheres; and when they are removed by the glass handles, all the electricity of the globe will be discharged, and will be retained on the exterior surfaces of the hemispheres.

The interior surfaces of hollow vessels have not any electricity distributed on them, because there is no opposing surface on which the electricity of the opposite kind can be induced. The inside of a hollow metal globe, for example, has opposed to it only the metal already charged with electricity of the same kind as its own; consequently, there can be no inductive action on such surface. The absence of electricity from the inside of charged metallic vessels may be shewn by electrifying a metal ice-pail or a pewter pot placed on an insulating stand, and then lowering into it a metal ball suspended by silk, allowing it to touch the inside. When the ball is withdrawn, it will not indicate the least trace of electricity; but if it be then applied to the outside of the metal vessel, it will acquire and carry away a large portion of the charge.

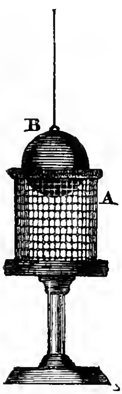


fig. 18.

A more striking exemplification of the diffusion of electricity exclusively on the outsides of vessels is afforded when, instead of a solid metallic vessel, a cylinder formed of wire-gauze is employed. Let the insulated ball B be lowered into the wire-gauze cylinder A, fig 18, when electrified and mounted on an insulating stand, and it may touch every part of the interior without receiving any portion of the electricity with which the exterior surface is charged, though the slightest touch on the other side of the open wire mesh would communicate its electricity to the ball.

When a wire-gauze cover is placed over an electrometer, it effectually prevents the gold leaves from being affected by excited electrics, and it is customary to cover all delicate instruments of the kind with a metallic net, to protect them from injury by too violent action.

The fact that by increasing the surface of any body charged with electricity the intensity is diminished, was known to Dr. Franklin, who illustrated this absorbing influence of ex-

tended surface by electrifying a chain heaped together on an insulating stand, and then drawing part of it upwards by a silk thread. When the surface capable of being surrounded by an electrical atmosphere was thus increased, the intensity of the charge was diminished, and by lowering the chain again the original force was regained.

Another mode of shewing the effect of enlarging the surface is to wind a strip of tinfoil round a small insulated wooden cylinder, as represented in the annexed woodcut. When a charge of electricity is given to the metal, the pith-balls *a, a* diverge. Take hold of the small piece of ribbon *b*, and draw some of the foil from the cylinder, so as to expose a large surface, and the balls collapse. On winding the foil again on the cylinder the balls again diverge. It is evident, therefore, that the quantity of electricity undergoes no change by the altered state of the surfaces, but that the intensity is diminished by the same quantity being diffused over a larger space. The difference in effect produced by expanding or contracting the surface over which a given charge of electricity is diffused will be further noticed when we speak of the electrical battery.

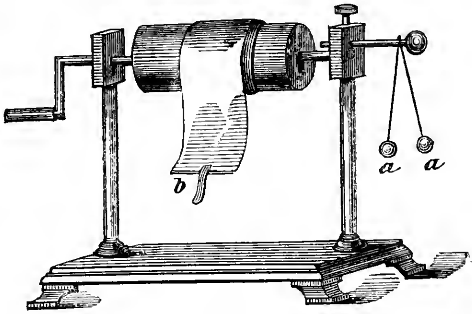


fig. 19.

Though the electrical charge resides on the surfaces of conductors, it does not exist as an atmosphere of electricity around them, as was formerly imagined; but it seems to be confined within the external surface. No difference is made in the distribution of electricity on metals when a part or the whole surface is covered with varnish, or even with a thick coat of wax.

The electricity excited by the electrical machine is in a high state of intensity; but the quantity is comparatively small. Its concentrated energy enables it to force a passage through the non-conducting air to a greater distance than when collected in much larger quantities in a lower state of intensity; but the physical effects of the long spark emitted are only feeble. They are sufficient however to shew, in addition to the general phenomena of attraction and repulsion which we have noticed, the igniting power of electricity in some of the more inflammable substances. If spirits of wine be warmed in a metal spoon, and a spark from the conductor be made to pass through the spirit, it will be instantly set on fire. This experiment appears the more curious when the spark is passed from the finger of a person placed on an insulating-stool.

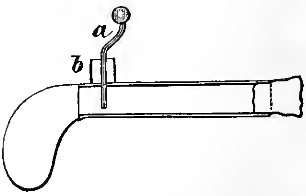


fig. 20.

Hydrogen gas may also be inflamed by a spark. For performing this experiment in the most efficient manner, an electrical cannon or pistol is con-

structed. It consists of a brass tube, about one inch in diameter and six inches long, closed at one end. A piece of wire *a*, fig. 20, that is to conduct the electricity through the gas, is introduced into the tube, but is insulated from it by ivory or wood, *b*.

The most convenient way of charging the pistol is to attach a tube to a bladder containing an explosive mixture of hydrogen and oxygen gases, to insert it perpendicularly into the mouth of the pistol, and then, by gently squeezing the bladder, to force the gas out. In this way the atmospheric air is displaced, and the cannon is charged without wetting the insulating ivory. The open end is then closed with a cork whilst the pistol continues to be held inverted, to prevent the escape of the hydrogen. On taking a spark from the machine through the wire, the gas explodes with a loud report, and propels the cork to a considerable distance.

In charging the pistol in this manner from a bladder filled with an explosive mixture of hydrogen gas, care should be taken not to allow a lighted candle to be brought near. From neglect of this precaution on one occasion, an accident happened to the author that produced considerable alarm. He was filling a gun-barrel with explosive gas from a bladder held under his arm, when, in consequence of approaching too close to the candle, the contents of the bladder exploded, extinguishing the lights and stunning his arm and side, though it did no serious damage.

The resistance offered by air to the passage of electricity may be very beautifully illustrated by sparks from the machine. If the air were a conductor there could be no manifestation of electrical phenomena, for the equilibrium would be restored as quickly as it was disturbed; but the resistance of the air serves to retain the excited electricity on the surfaces of electrified bodies. When the electricity possesses sufficient intensity to force its way through the resisting air, the discharge is accompanied by a bright spark. If the machine be powerful and in good order, sparks eight or ten inches long may be obtained, which, in overcoming the resistance of the non-conducting medium, are diverted from a straight path and describe a ziz-zag course, resembling a flash of forked lightning.

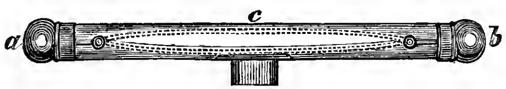


fig. 21.

That the resistance to the passage of electricity from body to body is caused by something more than by the intervening space, is proved by the facility with which electrical discharge is effected through vessels exhausted of air. For instance, let a glass tube C, fig. 21, about three inches in diameter and two feet long, be fitted at each end with a brass cap, to which a wire and a brass ball are attached. At the end B there is a screw to fit on to the air-pump, by which the tube may be exhausted. On applying one end to the prime conductor, and the machine is put in action, the electricity passes readily through the partial vacuum, and is discharged through the tube. When the experiment is performed in the dark, the interior of the tube will be observed to be luminous with beautiful purple-coloured flashes, which present a miniature resemblance to the aurora borealis.

If the air be gradually admitted whilst the machine continues in action, and the tube be removed a short distance from the conductor, so that sparks may pass between them, the resistance to the electricity will in-

crease as the air is admitted, until the sparks can no longer force a passage. At an early stage of the re-admission, when the air is still greatly attenuated, the electric spark will pass through like a ball of light, moving comparatively slowly, so that its form and course may be distinguished. This very interesting experiment, which requires a little address for its perfect development, exemplifies the phenomena of meteors or "falling stars" in the upper regions of the atmosphere, where the air is less rarefied than in the higher fields of space where the aurora coruscates.

Faraday has examined with great care the various kinds of electrical discharge, with a view to establish his theory of induction; and he has succeeded in accumulating a great number of interesting facts connected with the transmission of electricity through resisting media. Faraday's theory of induction, as we have before stated, supposes that the particles of non-conducting bodies, when acted on by an electric force, assume a polar state, and form a chain of contiguous particles, each one of which has a positive and negative end. This polarised chain of particles, it is assumed, extends from the excited electric through the air or other non-conducting body, and induces in the nearest conducting body a state of electricity opposite to that of the coercing force. In proportion as the particles of different substances possess the power of communicating electricity to each other, their tendency to assume a polar condition diminishes; and, on the other hand, the greater the non-conducting property of the particles, the more strongly will they take the polar direction. In other words, induction can only take place across insulating substances, and the inductive action is more or less readily assumed according to the power of conducting electricity.

Applying this theory to the explanation of electric discharge through resisting media, Faraday assumes that there is a limit to the influence which the intervening chain of polarised particles possesses in retaining the attracting forces apart, and that when any of the contiguous particles have attained their highest degree of polarised exaltation, they can no longer resist the passage of the electric force. Thus when one or more links of the chain are subverted, the two forces cannot be restrained. Every case of discharge is therefore preceded by inductive action which coerces the insulating particles into a polar state, until they are restored to their natural condition by the overpowering attraction of the combining forces.

The electric spark is considered "as a discharge or lowering of the polarised inductive state of many dielectric particles by a particular action of a few of the particles occupying a very small and limited space, all the previously polarised particles returning to their first or normal condition in the inverse order in which they left it, and uniting their powers meanwhile to produce, or rather to continue, the discharge effect in the place where the subversion of force first occurred."

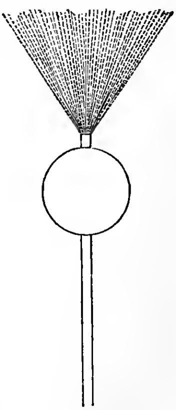


fig. 22.

The sudden restoration of the electrical equilibrium by the mutually-attracting forces bursting through the intervening non-conducting space, is termed *disruptive discharge.* It may

take place either in the form of a spark or in a series of rapidly-intermitting discharges, so near together as to appear continuous. The latter is called the *brush discharge* (fig. 22), from the form of its luminous coruscations.

To produce the brush discharge with effect requires the machine to be in good order, and the intensity of the electricity on the prime conductor to be increased by adding to it a projecting rod with a rounded end. The discharge takes place from the end into the air, or to any conducting body brought near, and it is accompanied with a continuous rushing noise. Professor Wheatstone has proved that the sound is produced by a rapid succession of disruptive discharges, and that the brush of light observable in a darkened room is resolvable into a number of brushes, each of which indicates a separate and instantaneous discharge; though the discharges are so rapid as to mingle together in one luminous expanding cone, with a bright apex near the discharging conductor.

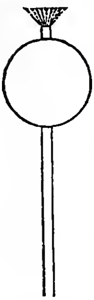


fig. 23.

The difference in the appearance of the brush discharge from the positive and negative conductors is very observable. The brushes obtained from the negatively-charged conductor (fig. 23) are shorter, and the discharges are more rapid, "being seven or eight times more numerous in the same period than those produced when the rod was charged positively to an equal degree."*

Another form of discharge is obtained when a fine point, instead of a blunted thick wire, is attached to the prime conductor. In that case, the expanding brush accompanied with a rushing sound gives place to a small pencil of rays, which produces a steady light. This has obtained the name of the *glow discharge*, *a*, fig. 24. It is probable that even this steady and noiseless discharge may be resolved, like that of the brush, into an innumerable quantity of intermittent discharges, mingled together so intimately as to be separately indistinguishable.

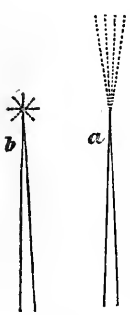


fig. 24.

When a fine point is attached to the insulated rubber of the machine, the light presents the form of a star, *b*.

The light of the electric spark varies as it passes through different media. In air the sparks have that intense light and bluish colour which are so well known, and often have faint or dark parts in their course when the quantity of electricity is not great. In nitrogen gas they have more colour of a bluish or purple character; and Faraday considers them remarkably sonorous. In hydrogen, the colour is crimson; in oxygen, whiter than in nitrogen, and not so brilliant; in carbonic acid gas similar to air, but with a green tinge, and remarkably irregular; in coal gas the spark is sometimes green, sometimes red, and occasionally one part green and another red, and the black parts occur very suddenly. These various colours of the spark in different gases are considered by Faraday to be attributable "to a direct relation of the electric powers of the particles of the dielectric through which the discharge

* Faraday's Experimental Researches.

occurs, and are not the mere results of a casual ignition, or a secondary kind of action of the electricity upon the particles which it finds in its course, and thrusts aside in its passage."*

The brush discharge also exhibits peculiar characters in the different gases, the effect in nitrogen being finer in form, light, and colour than in any other gas, and evolving a greater quantity of light. The peculiar character of nitrogen in relation to the electric discharge must, it is supposed by Faraday, have an important influence over the form, and even the occurrence of lightning, as that gas, which extends its discharge farther than any other, constitutes four-fifths of the atmosphere.

CHAPTER VII.

ACCUMULATED ELECTRICITY.

The Leyden jar—Its construction and mode of action—The amount of electricity always constant—Chain of Leyden jars self-charged—The charge in the glass, and not in the coating—Charged plate of glass—Electrical batteries—Intensity of force diminished by extension—Residual charge—Lateral charge: its cause and effects—Distribution of electricity during discharge—Universal discharger—Lane's discharger—Quadrant electrometer.

THE power of accumulating electricity by means of the Leyden jar has placed in the hands of electricians a force of almost unlimited extent. In our sketch of the history of electric science, we have already adverted to the nature of the apparatus. As at present constructed, it consists of a thin glass jar A, fig. 25, coated within and without with tin-foil, which reaches to about three inches of the top. A wooden cover B serves as a support to a straight thick brass wire C, that passes through the centre of the cover, and has a metallic connexion by a chain or wire with the interior coating. This wire rises a few inches above the cover, and is surmounted by a hollow brass ball, which is screwed on to the top of the wire to prevent the dispersion of the electricity from the end. The sizes of the jars vary from half-a-pint to ten gallons. One holding about a pint will give a shock as strong as most persons like to receive.

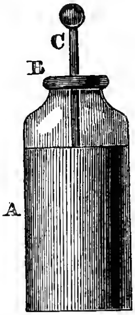


fig. 25.

To charge a jar with positive electricity, connect its small brass ball with the prime conductor of the machine, and make a connexion between the outside coating and the ground. When fully charged, it will give indications of its electrical condition by a muttering sound; and in the dark, rays of light will be seen issuing from the edges of the tin-foil and from the ball.

The notion of Muschenbrœck, which led to the discovery of the Leyden jar, was to collect electricity within a phial to prevent its dispersion, and thereby to store up an increased quantity of the electric fluid; but it is

* Experimental Researches.

now ascertained that a jar when highly charged does not contain more electricity than it did before it was applied to the conductor. The effect produced by charging is not to increase the quantity, but only to disturb the natural electricity previously present in a latent state on the inside and outside of the glass. There is injected into the inside, by connexion with the electrical machine, an amount of positive electricity, whilst an equal amount of negative electricity is driven from the outside by the force of electrical induction; and unless the electricity on the outer surface of the glass can be thus driven off by affording it a connexion with the ground, the inside cannot receive a charge.

Let a Leyden jar be insulated from the earth by placing it on a glass stand, and it will receive scarcely any electricity from the conductor; not more than equal to the quantity which can escape from the outside to the surrounding air. If the knob of another insulated jar be connected with the ground, and the outside coatings of the two jars be brought near together, sparks will then pass rapidly from the prime conductor to the knob of the first, and they will also pass as rapidly between the outside coatings of the two jars. In this manner both the Leyden jars become charged, and it will be found that they are charged equally, but with electricity of opposite kinds. The first one, that derived its electricity directly from the prime conductor, will be charged positively; the second, that derived its charge from the electricity escaping from the knob to the ground, will be negative. Place the two jars on the table, and suspend between them a pith ball B or other light substance, and it will be attracted alternately from one to the other in rapid vibrations, clearly shewing that the electricity in the two jars is of opposite kinds.

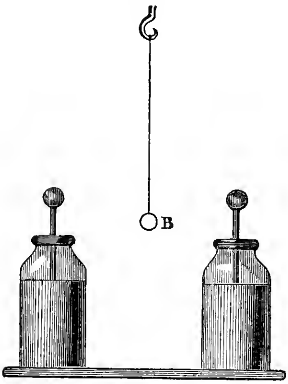


fig. 26.

The phenomena that occur during the charge of a Leyden jar have been adduced as evidence in support of the Franklinian theory of a single electric fluid, the outside being supposed to be in a *minus* state after parting with its natural quantity to the other jar. But the phenomena are explicable also on the hypothesis of two fluids, it being assumed that they are separated from their neutral state by the coercing force of the free electricity communicated to the inside of the jar.

Franklin attempted to apply practically the charging of one jar from the escaping electricity of another. He inferred, that if a series of insulated jars were arranged with the outside coatings and knobs alternately touching, the coating of the last one being connected with the ground, that by this arrangement the positive electricity expelled from the outside of the first jar would charge the second; that the electricity from the outside of the second would charge the third positively, and so on to any number; and that an immense electric force might be thus accumulated from the same quantity of electricity that is required to charge a single jar.

Let A B C represent a series of three jars, A and B being mounted on

insulating glass stands. On making connexion from the prime conductor of an electrical machine to the knob of A, that jar will be charged positively, and an equal amount of electricity will be expelled from the outside into B, which will also be positively charged. The third jar C will in like manner be charged from the outside of B, and the electricity which was expelled from A, on arriving at the outside of the last jar of the series, will be conducted to the earth.

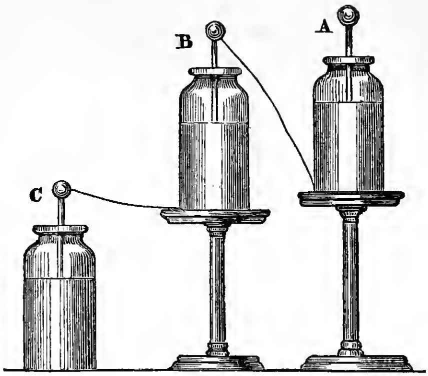


fig. 27.

To effect the discharge of a jar, it is requisite that a connexion be made between the positive electricity within and the negative electricity without, so that the equilibrium may be restored. Now if a metallic connexion be made from the knob of B to the knob of A, there will be a discharge of the first jar only; for though the connexion is made with the knob of B, none of the positive electricity within can be discharged, for it is restrained by the coercing force of the opposite electricity on the outside. If metallic connexion be made between the outside of B and the knob of A, both those jars will be discharged, and the third will remain charged; but by bringing a wire from the outside of C to the knob of A, the three jars will be at once discharged.

We have been led away by the phenomena exhibited in charging the Leyden jar from the consideration of the cause of its accumulating electricity, and discharging the force instantaneously. We have stated that the cause depends on inductive action operating through the substance of the non-conducting glass. Exemplifications of this action through glass have been previously given. It was shewn that a pane of glass when excited by friction on one side, has negative electricity induced on the other, and that a glass tumbler may be charged with electricity by exposing the inside to the influence of an electrified point, whilst the outside is grasped by the hand. The electricity thus collected on the surfaces of the pane of glass and the tumbler is sluggish in its action, and is dissipated by slow degrees, on account of the non-conducting property of the glass surfaces; but if metal plates be applied on each side of the pane of glass, the electricity is instantly concentrated at any point, and on connecting the two surfaces with a wire, a discharge takes place, exactly as in the Leyden jar. The charged tumbler might also be converted into a Leyden jar by the application of interior and exterior casings of metal foil, to serve as conductors, to concentrate at any point the electricity distributed over the surface of the glass.

To prove most conclusively that the charge of a Leyden jar is retained on the surface of the glass, and not in the metallic coatings, Leyden jars are made with tin inside and outside casings, so contrived that they may be easily removed. A jar of this kind, when charged and placed on an in-

sulating stand, may have the metal casings removed and others substituted for them ; yet after this change the jar will be found to retain its charge. The metal serves only to conduct the electricity simultaneously from all parts of the glass.

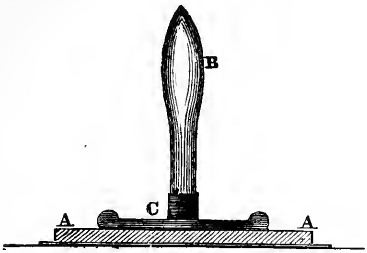


fig. 28.

A plate of glass affords the most convenient mode of illustrating that the electrical charge is retained by the glass and not by the metal. Let a pane of glass A A, fig. 28, about one foot square, be covered on one side with tin-foil, and laid horizontally on the table. To the other side apply the insulated metal disc C of an electrophorus ; connect the disc with the prime conductor, and a few turns of the machine will charge the glass. Remove the disc by the insulating handle B, and it will manifest scarcely any trace of electricity. Let the same or another disc be again applied to the surface of the glass, and on making connexion between the metals on the opposite sides a strong discharge will take place. A movable metal disc might be applied to each surface of the glass with similar results; but the arrangement indicated in the figure is more convenient.

When a more powerful charge of electricity is required than a single jar will retain, several are combined to form an electrical battery. For convenience, the jars are placed in a box with divisions, the bottom being

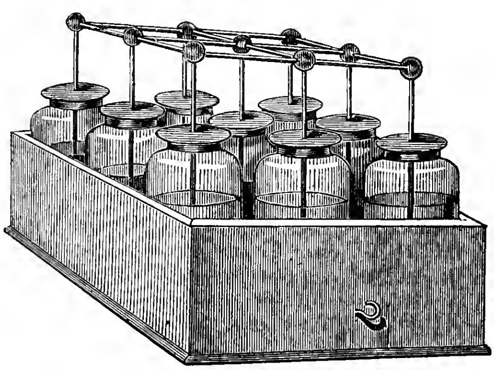


fig. 29.

lined with tin-foil, to make connexion with all the exterior coatings. The knobs of the jars are connected together by wires, as represented in fig. 29 ; and there is a metal hook projecting from the side of the box connected with the tin-foil lining. Thus all the interior and all the outside coatings of the jars are connected; and when communication is made between the prime conductor and any of the knobs of the jars the whole are simultaneously charged. They are also discharged simultaneously by making connexion between the projecting hook and any one of the knobs.

The combination of several small jars is found better than having a smaller number of large ones, because the thickness of the glass necessary in jars of large size obstructs induction through it. By an arrangement of many jars, an amount of electric force may be accumulated that would almost equal the destructive power of lightning. The battery used by Faraday in his experiments consisted of fifteen equal jars, coated eight inches upwards from the bottom, and twenty-three inches in circumference; so that each contained 184 square inches of glass coated on both sides, independently of the bottoms of the jars, which were of thicker glass, and contained each about fifty square inches. The total coated surface of the battery consequently comprised 3500 square inches of coated surface. The electrical battery at the Polytechnic Institution exposes a coated surface of nearly eighty square feet. To receive the full charge of such a battery would be instant death. A battery of nine quart jars is sufficient to exhibit the deflagrating effects of electricity on a small scale; nor would it be safe to receive a shock from a battery of that size.

It is a fact deserving consideration that the accumulation of quantity diminishes the intensity of electricity. For instance, an electrical machine when in good action will emit sparks four inches long. When a Leyden jar is charged with twelve such sparks, the accumulated electricity will not force its passage through more than a quarter of an inch; and if the same quantity be distributed among the jars of an electrical battery, the discharge will not take place through the eighth of an inch. The quantity of electricity is in each case the same, but the state of intensity diminishes in proportion to the surface over which it is diffused. The difference between quantity and intensity is still more remarkably manifested in the different conditions of frictional and voltaic electricity, as will be subsequently noticed.

One of the peculiar phenomena of the electrical battery is the *residual charge.* When communication is made between the inside and outside coatings of a battery consisting of several jars, the whole of the electricity is not immediately discharged. On again making connexion between the inside and outside coatings, after a short interval, a second discharge will occur; which, though comparatively feeble, might occasion a disagreeable shock. The cause of this residual charge is partly attributable to the accumulation of electricity on those parts of the jar just above the metallic coating; which portions, not being in direct contact with the metal, are not conducted with equal rapidity. Part of the charge also enters into the pores of the glass, and is thus removed from immediate contact with the metal.

The simplest kind of instrument employed for discharging a Leyden jar or an electrical battery is a thick curved piece of brass wire, fitted with a small ball at each end. One of these balls is applied to the outside coating, and when the other is brought near to the knob of the jar the electricity instantly passes through the wire with a smart snap or report, connexion being thus made between the two charged surfaces of the jar. When, however, a discharger of this kind is employed for an electrical battery a slight shock is felt, owing to what is termed the *lateral discharge;* therefore, to avoid the inconvenience and the danger that might arise from holding the wire in the hand, an insulated wire is generally employed. Its form is represented in fig. 30, as applied in discharging a

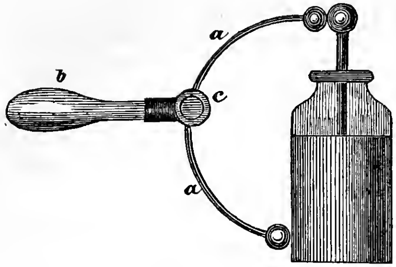


fig. 30.

Leyden jar. Two thick brass wires *a a*, of equal lengths, and terminated with brass balls, are jointed together at *c* for the convenience of adjustment, and are cemented to a glass handle *b*, which serves to insulate the wires from the hand, and prevents the liability of any perceptible portion of the charge being received by the operator.

There has been much discussion among electricians on the subject of lateral discharge, in reference more particularly to the safety of lightning-conductors; we shall therefore notice in this place the cause of the phenomenon.

It is the case with electricity, even to a greater extent than with all fluid bodies, that it will discharge itself into every channel that is open to it. Thus, as in a mountain-torrent some portion of the water will deviate from the straight and broad course into circuitous and narrow crevices, so will the highly tensive electric fluid force its passage through every conducting medium, even though the course directly open to it appears to offer a free passage. It must be borne in mind, however, that as every water-course offers some obstruction to the current, so does even the best conductor offer resistance to the electric fluid; some portion of which is consequently diverted through every conducting substance by which it can be transmitted. Thus, when a Leyden jar is discharged with an insulated wire, a small part of the charge passes through the circuitous and comparatively obstructive course offered by the body of the operator, by the floor, and by the table whereon the jar is placed. In the case of a single jar, the quantity of electricity that passes in that direction is imperceptibly small; but when several jars are combined, the lateral discharge may become unpleasantly strong, especially if the wire of the discharging-rod be not very thick. Even when an insulated discharging-rod is employed, we may infer that some portion of electricity will force its way along the glass; but it is so infinitessimally small as to be inappreciable.

Applying the experience and inferences deducible from experiments with the electrical battery to the more powerful effects of lightning, we are led to consider that every flash of lightning must be accompanied by lateral discharge, and that the quantity thus diverted from the direct and easiest path between the clouds and the earth will depend on the amount of resistance which that direct course offers. Therefore, though lateral discharge must, to some extent, always occur, it may be rendered entirely innocuous by a sufficiently thick and unbroken lightning-conductor. In the Report of a Committee appointed by the House of Commons to examine the plan produced by Sir William Snow Harris for protecting ships from lightning, several eminent scientific men expressed their opinions that no lateral discharge could occur with uninterrupted conductors of sufficient thickness. These opinions could, however, only have had reference to any possible danger likely to arise from the division of the charge in

other directions; for it has been satisfactorily proved, that during an electric discharge and the transmission of an electric current, some portions will be diverted into every possible path.

Reverting to the consideration of the electrical battery and the apparatus connected with its application, we must notice particularly the "universal discharger" as an instrument of very general utility in electrical experiments. It consists of a wooden base A, into which are inserted three upright pillars. The two outermost pillars are of glass, for the purpose of insulating the ball-and-socket joints C C, through which brass rods B B slide, so as to bring them to any required distance on the small table D, which is supported on the central pillar E. The table may be raised to any height, and fixed by a screw. The outer coating of the Leyden jar or battery is connected with one of the rods, and the insulated discharger being connected with the other by means of a chain, the charge of the battery is thus very conveniently sent through any substance placed on the table between the ends of the two rods.

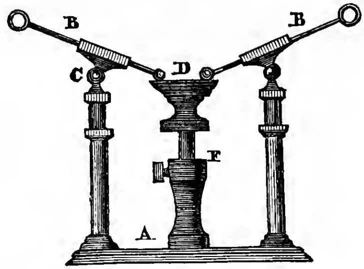


fig. 31.

Lane's discharger is frequently very useful in connexion with the preceding instrument, as it is self-acting, and transmits a succession of charges of regulated power. Fig. 32 will afford a correct idea of the construction of this apparatus. A bent glass rod C is attached to the wire of a Leyden jar, and on the top of the bent arm is a brass ball, through which the horizontal wire D slides, so as to regulate the small ball at the end of it to any required distance from the knob of the jar. A wire or chain E connects the horizontal wire with the outside of the jar; and in its course may be placed the universal discharger or any substance to be operated on. It is evident from this arrangement that the discharge of the Leyden jar will take place whenever the electricity has attained a degree of intensity sufficient to overcome the resistance of the air in the space between the knob of the jar and the ball of the discharger; and by the proper regulation of that distance a succession of charges of nearly equal strength may be transmitted without any interference with the apparatus. This kind of discharger is sometimes attached to the prime conductor of the electrical machine as a more convenient mode of appliance.

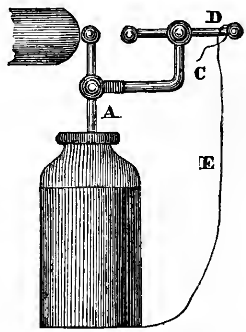


fig. 32.

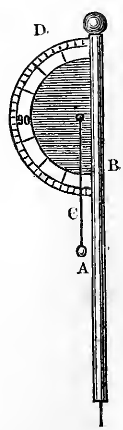


fig. 33.

For ascertaining the intensity of charge, an instrument constructed on the principle of the pith-ball electrometer is usually attached to the prime conductor. It is called Leslie's quadrant electrometer,

represented in fig. 33. The pith-ball A, attached to a light but rigid stem C, is suspended from the upright conducting pillar B, and is repelled proportionally to the intensity of the electricity in the Leyden jar or battery connected with the prime conductor. The quadrant D is graduated to mark the degree of repulsion, and by this means, and with the aid of Lane's discharger, the intensity of any charge or succession of charges may be known and regulated.

CHAPTER VIII.

MISCELLANEOUS PROPERTIES AND EFFECTS.

The electric shock: its physiological effects—Heating power of the electrical battery—All electrical effects consequent on resistance—The electric light: its instantaneous duration calculated—Magnetising and decomposing power of static electricity.

NEARLY all the properties of accumulated electricity may be exemplified by means of a cylinder machine of nine inches diameter and a battery of nine quart jars, assisted with the accompanying apparatus which we have described. Many of the phenomena we are about to notice require only a single jar for their development.

The sudden contraction of the muscles by the peculiar action of electricity on the nerves is at all times startling and disagreeable, and when the sensation of the shock was quite novel and the consequences unknown, it was calculated to excite fear, though we now ridicule the exaggerated accounts first given of the sensation. We have already noticed the remarkable effect of a charge sent through the brain, as described by Dr. Franklin in his dangerous-seeming experiments; but without venturing on such powerful charges as he distributed without fear, the sudden loss of muscular power may be illustrated by sending a comparatively small shock from a single jar through the spine. When a powerful charge is sent through the lungs it is said to cause a violent shout; and a much smaller charge through the same organ occasions involuntary laughter. The derangement of the nerves by the sudden shock has the effect of causing, in nervous persons, continued trembling of the limbs for some time afterwards; and a frequent repetition of shocks is by no means desirable.

When the powerful influence exerted by electricity on the nervous system was discovered, great hopes were entertained that it would prove a valuable remedial agent. These hopes have, however, for the most part been disappointed. Several instances, indeed, are recorded of wonderful cures effected by electrical agency, though they seem to have been more dependent on the imagination than on the direct influence of electricity. In cases of chronic rheumatism rapid successions of feeble electric shocks or vibrations have been found to afford relief; but generally speaking the application of electricity to medical purposes has hitherto failed of success, probably from ignorance of the means by which its powers may be rendered serviceable.

Of the experiments made on living creatures with a view to ascertain

the amount of charge sufficient to produce death, those on eels are the most curious. Difficult as it is to deprive them of life by ordinary means, they are killed instantly by a powerful electric charge; and when such a charge is sent through a part only of the body of an eel, that portion is deprived of life, while the other part continues to exhibit signs of vitality. It has been observed that the bodies of animals killed by electricity very quickly decompose; and this fact seems to explain what Franklin was inclined to conceive a mere "fancy," when he thought that a turkey killed by electricity ate remarkably tender.

The fusing power of electricity was known before it was acknowledged to possess the property of imparting heat; and some of the early electricians entertained the notion that the dissipation of thin leaves of metal by the electrical battery was produced by what was termed "cold fusion."

Some illustrations of the igniting power of the electric spark have been already mentioned; but to exhibit the heating effects of electricity on metals, and other less inflammable substances, requires an electrical battery containing a considerable amount of coated surface.

Let a thin strip of gold, silver, or copper leaf be attached by moisture between the rods of the universal discharger, and connect one of the rods with the outside coatings of the battery-jars. When the battery is fully charged, as indicated by the elevation of the ball of the quadrant electrometer, apply one of the knobs of the insulated discharging-rod to the second rod of the universal discharger, and bring the other knob in connexion with the inside coatings of the battery-jars. The charge will thus be sent through the strip of metal-leaf, which will be instantly deflagrated. If the metal-leaf be laid upon paper, the part whereon it was placed will be burnt, and traces of metallic oxide will remain. A small length of very fine wire may be deflagrated in the same manner.

The deflagration of the metal-leaf and of the wire are caused by the resistance they offer to the passage of the electric charge; for if they be a little thicker, so as to allow the electricity to pass more freely, the metals will be made red hot without being melted. It is, indeed, only by the resistance bodies offer to the passage of accumulated electricity that its presence is manifested. Through metals sufficiently thick to conduct it freely, electricity passes without any sign; but a similar charge sent through an imperfect conductor may produce destructive effects, in consequence of the resistance it encounters. This observation applies to all electric action whatsoever. *The manifestation of electricity is a proof of resistance offered to its passage; and when the resistance is decreased the electrical effects are proportionally diminished.*

The following experiment affords a satisfactory illustration of the increase of effect by increasing the resistance. Paste a broad strip of tin-foil across a small piece of sheet-glass; on the top of it place a corresponding piece of glass, perfectly dry, and press both together with a weight. The charge of a battery may thus be sent through the tin-foil without any perceptible effect. Cut away a small part of the foil, so as to leave a break in the middle about the sixteenth of an inch. The battery-charge may even then be sent between the glasses without injury, but the electricity will manifest itself by a bright spark at the point of separation in the foil. Increase the interval by cutting away another portion of the

foil, so that the resistance to the electric fluid may be increased, and on then repeating the discharge the glass will be shivered.

A piece of apparatus called a "thunder-house," constructed for the purpose of shewing the action of lightning-conductors, illustrates very satisfactorily the effect of interposed resistance to the course of the electric charge. A piece of mahogany about an inch thick is shaped into the form of the gable end of a house, A, fig. 34; and there is a small square wooden shutter, D, that may be easily taken out and placed at opposite corners. A strong wire, B C, rises above the chimney, passes down the house and across the shutter to the wire that connects with the outside of a large Leyden jar. When the jar is discharged through the wire, in the position represented in the diagram, the shutter retains its place, for the electric circuit is not interrupted; but if the shutter be turned, so that the wire may be in the direction marked by the dotted lines, the continuous circuit is broken, and the resistance which the electric fluid meets with in crossing the intervening space causes the shutter to be forced out to some distance.

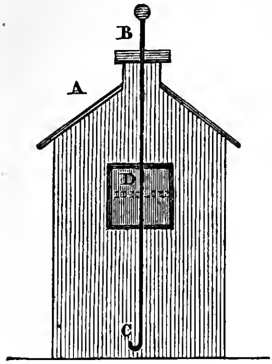


fig. 34.

The discharge of a Leyden jar may be prolonged by interposing an imperfect conductor; and by thus diminishing the rapidity of the passage of the electric fluid, it will produce effects that its more rapid action renders unattainable. Thus, if a small quantity of gunpowder be laid on the table of the universal discharger, the effects of an ordinary discharge will disperse the powder without igniting it; but if the metallic circuit be interrupted by a basin of water interposed between two ends of the connecting wires, the discharge is prolonged by the resistance of the water, and the force, though less energetic, is more effectual in igniting the gunpowder, which then explodes instead of being dispersed.

Several forms of apparatus have been contrived for exhibiting the electric light. Spangles of tin-foil are pasted on to glass, in various patterns, so arranged as to form a continuous line for the passage of the electric fluid. By means of Lane's discharger a continuous stream of small charges is sent through these breaks in the conducting metal-foil, at each of which a brilliant spark appears, representing in vivid lines the device arranged by the disposition of the breaks in the foil. In the dark this exhibition has a very agreeable effect; and when a lengthy device is patterned on the glass, the simultaneous appearance of sparks at all the breaks serves to shew, in some degree, the instantaneous character of the electric discharge. In the arrangement of the tin-foil spangles in devices, care must be taken that the sum of the spaces between each is not greater

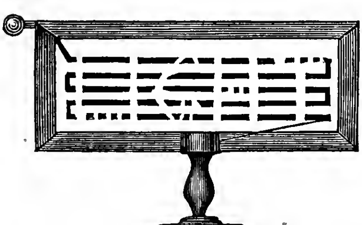


fig. 35.

than the space through which the electricity of the jar will discharge itself. Sparks from the prime conductor of the electric machine will traverse over a much greater space than a discharge from a Leyden jar, but the light is not so intense. A suspended chain also serves to exhibit the brilliancy and instantaneous nature of the electric discharge; for vivid sparks appear at the junctions of the numerous links; and when the chain is hung in festoons, luminous tracery is produced.

The instantaneous duration of the electric spark is shewn in a striking manner by a very ingenious application, by Professor Wheatstone, of one of the properties of vision. The retina of the eye, it is well known, possesses the peculiar property of retaining the impression of an image for the eighth part of a second after the object that produced it is removed. The eighth part of a second may perhaps seem to most persons a duration inappreciably small; but those accustomed to note time will detect, with the naked eye, a variation of the tenth part of a second in the vibration of a pendulum, and by means of the copying electric telegraph a variation of the thousandth part of a second may be detected and rendered visible. The fact that a lighted stick, when whirled round in the air, appears like a circle of light, proves also that the circle must be completed within the eighth part of a second, otherwise the line of light would appear to be broken; but as it is, the impression at every part of the circle remains on the retina until the light returns to the same point to renew it; and thus the circle described by the lighted stick, instead of appearing to be made up of numerous sparks, resembles a continuous ring of light. The same cause also explains why a circular screen containing figures or patterns painted on it becomes a confused mass of colour when turned rapidly round. It may be easily conceived, however, that if only *instantaneous* sight could be obtained of either of the whirling bodies, it would be seen in its true form; that is, the lighted stick would appear as a stationary spark, and the figures on the screen would be distinctly visible, and would seem to be stationary, though in reality revolving very rapidly. It is by applying this principle that Professor Wheatstone has determined the duration of the electric spark. A painted screen is turned round rapidly in the dark, and is lighted at intervals by electric sparks from a Leyden jar. The figures on the screen seen by this occasional light appear quite distinct, and to be at rest; thus proving that the duration of the light must be considerably less than the eighth part of a second. The velocity of the screen's motion is regulated to a known number of revolutions in a second, and by increasing the rapidity a speed is at length attained at which the colours become confused; even the duration of the electric spark affording time for the objects to be seen in more than one position. The rapidity of revolution being known, and also the duration of impressions on the retina, the length of time that light is thrown on the screen just before the figures become confused may be estimated; and thus Professor Wheatstone has been enabled to prove that the duration of the electric spark is not longer than the millionth part of a second. The electric spark seems, indeed, to be much longer in sight; but the retention of the light by the retina causes the duration of the impression to remain for the eighth part of a second, though the light itself only lasts the millionth part of that time. A flash of lightning is equally instantaneous, and all objects in motion seen in the night-time by lightning appear to be at rest. Even

a cannon-ball in rapid flight would appear to be motionless in the air. "As quick as lightning" has become a proverbial expression, though few persons are aware how very instantaneous it really is.

The magnetising and decomposing powers of electricity will be noticed more particularly when we come to speak of that modification of the force exhibited in the voltaic battery; but a few examples of the exercise of those powers by statical electricity will serve to shew that in these, as in all other respects, there is a similarity between the chemically excited and the frictional agent.

Let a sewing-needle be placed on the table of the universal discharger, so that several charges of the electrical battery may be sent through it in quick succession. This can be most conveniently done by connecting Lane's discharger with the instrument. After the needle has been thus operated on, it will be found to possess magnetic properties, and the effect will be increased if the needle be placed in the magnetic meridian during the experiment.

The decomposing power of statical electricity may be shewn by passing a succession of electric sparks from the machine through litmus or turmeric paper moistened with a solution of sulphate of soda. The salt is shortly decomposed by the electric agency; and the acid liberated from the soda will turn the paper red if litmus be used, or if turmeric paper be the re-agent, the alkali separated from the acid will give it a brown stain. The experiment succeeds better when the electricity is directed from the prime conductor to the paper by points, or by some other form of discharge which will cause a constant current of electricity of a lower degree of intensity to act on the salt to be decomposed.

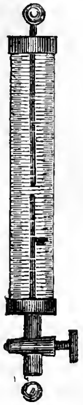


fig. 36.

The decomposition of water may be illustrated by passing a rapid succession of charges from a Leyden jar between the ends of two wires inserted in a glass tube containing water, the ends of the two wires in the water being about half an inch apart. At each discharge small bubbles of hydrogen and oxygen gases rise from the ends of the wires in the proportion of two parts of hydrogen to one of oxygen, that being the proportion in which the two gases combine in the constitution of water. The gases thus evolved, if mingled together, will explode when a light is brought near; and if the experiment be conducted with great care, and on a sufficiently large scale, a quantity of water will be formed by the re-union of the gases during the explosion, exactly corresponding in weight to that of the water decomposed.

CHAPTER IX.

ATMOSPHERIC ELECTRICITY.

Beccaria's observations of a thunder-storm—Mr. Crosse's apparatus and experiments—Remarkable phenomena of a thunder-storm—Different conditions of artificial electricity and lightning—Lightning-conductors—Supposed danger from lateral discharge—Various kinds of lightning-conductors—Safest place in a thunder-storm—Causes of the electrical state of the clouds—Sheet-lightning and forked-lightning—Thunder—The aurora borealis.

THE identity of lightning and electricity was fully proved by Franklin and by the French electricians, who succeeded, by experimenting according to his directions, in drawing lightning from the clouds. The fact was so completely established by the first experiments on the subject as to leave no doubt that lightning is the effect of electrical discharge between the earth and the clouds; and the principal object of succeeding investigations has been to determine the peculiar conditions of the electricity of the clouds, the means by which they become charged, the force of the disruptive discharge, and the most effectual means of guarding against its effects.

Signor Beccaria, of Turin, a contemporary of Franklin's, made a careful and very extended series of observations on lightning and atmospheric electricity, which have scarcely been surpassed by those of succeeding electricians. In his experiments he made use of kites and pointed rods, and of a great variety of both at different places. He paid particular attention to the appearances presented by the clouds during thunder-storms, of which the following were the most remarkable: "The first appearance of a thunder-storm is one or more dense clouds increasing very fast in size, and rising into the higher regions of the atmosphere. The lower surface is black and nearly level, but the upper finely arched and well defined. Many of these clouds seem often piled one upon another, all arched in the same manner, but they keep continually uniting, swelling, and extending their arches. At the time of the formation, or approach of the dense cloud, the atmosphere is generally full of a great number of separate clouds, motionless and of peculiar shapes. All these, on the appearance of the thunder-cloud, draw near towards it and become more uniform in their shapes as they approach, until they coalesce into one uniform mass. When the thunder-cloud has increased to a great size its lower surface is often ragged, particular parts being detached towards the earth, but still connected with the rest. Sometimes the lower surface swells into various large protuberances, bending uniformly towards the earth; and sometimes one entire side of the cloud will have an inclination to the earth, and the extremity will nearly touch the ground. When the eye is under the thunder-cloud, after it has grown large and well-formed, it is seen to sink lower, and darken prodigiously; at the same time that a number of small clouds are seen in rapid motion driving about in very uncertain directions under it. Whilst these clouds are agitated with the most rapid motions the rain generally falls in the greatest plenty, and if the agitation be exceedingly great, it generally hails.

"While the thunder-cloud is swelling and extending in branches over a large tract of country, the lightning is seen to dart from one part of it to another, and often to illuminate the whole mass. When the cloud has acquired sufficient extent, the lightning strikes between the cloud and the earth in two opposite places, the path of the lightning lying through the whole body of the cloud and its branches. The longer this lightning continues, the rarer does the cloud become, until at length it breaks in different places and shews a clear sky. When the thunder-cloud is dispersed, those parts which occupy the upper regions of the atmosphere are equally spread and very thin, and those underneath are black, but also thin; and they vanish gradually without being driven away by any wind, being dissolved into invisible vapour."*

Experiments on a scale of vast magnitude have been for some years past conducted by Mr. Crosse, of Broomfield, near Taunton, a gentleman who, secluded within his own domain, which he has converted into an extensive electrical laboratory, has been endeavouring to dive into the secrets of nature, and to trace the agency of electricity in the construction of rocks, and even in the creation of living creatures. This philosopher collects electricity from the atmosphere by means of what he terms an "exploring wire," which extends for several miles over his grounds. This wire is insulated, and is connected with many pointed metal rods, which are supported and insulated on poles fixed to some of the highest trees in his park. These poles are erected in all directions, as far as the eye can reach, and the exploring wire connected with them is made to terminate outside the window of the laboratory. A thick wire communicating with the earth is supported on a pole near to the exploring wire, to serve as a safety conduit for the electricity when it is emitted in such quantities as to become dangerous. When experiments are performed in the laboratory with the accumulated electricity collected by the exploring wire, it is introduced through the window by a connecting wire; convenient arrangements being made for applying the force with advantage and for securing the safety of the operator.

The following is Mr. Crosse's account of the construction of a thunder-cloud, as examined by the exploring wire; and of his views of the manner in which the electricity is distributed:

"On the approach of a thunder-cloud to the insulated atmospheric wire, the conductor attached to it gives corresponding signs of electrical action. In fine cloudy weather the atmospheric electricity is invariably positive, increasing in intensity at sun-rise and sun-set, and diminishing at mid-day and mid-night, varying as the evaporation of the moisture in the air; but when the thunder-cloud (which appears to be formed by an unusually powerful evaporation, arising either from a scorching sun succeeding much wet, or *vice versa*) draws near, the pith balls suspended from the conductor open wide with either positive or negative electricity; and when the edge of the cloud is perpendicular to the exploring wire, a slow succession of discharges takes place between the brass ball of the conductor and one of equal size carefully connected with the nearest spot of moist ground. I usually connect a large jar with the conductor, which increases the force, and in some degree regulates the number of the explosions; and

* Priestley's History of Electricity.

the two balls between which the discharges pass can be easily regulated, as to their distance from each other, by a screw. After a certain number of explosions, say of negative electricity, which at first may be nine or ten in a minute, a cessation occurs of some seconds or minutes, as the case may be, when about an equal number of explosions of positive electricity takes place, of similar force to the former, *indicating the passage of two oppositely and equally electrified zones of the cloud*; then follows a second zone of negative electricity, occasioning several more discharges in a minute than from either of the first pair of zones; which rate of increase appears to vary according to the size and power of the cloud. Then occurs another cessation, followed by an equally powerful series of discharges of positive electricity, indicating the passage of a second pair of zones: these in like manner are followed by others, fearfully increasing the rapidity of the discharges, when a *regular stream commences*, interrupted only by change into the opposite electricities. The intensity of each new pair of zones is greater than that of the former, as may be proved by removing the two balls to a greater distance from each other. When the centre of the cloud is vertical to the wire, the greatest effect consequently takes place, during which the *windows rattle in their frames*, and the bursts of thunder without and the noise within, every now and then accompanied by a crash of accumulated fluid in the wire striving to get free between the balls, produce the most awful effect, which is not a little increased by the pauses occasioned by the interchange of zones. Great caution must of course be observed during this interval, or the consequences would be fatal. My battery consists of fifty jars, containing 73 feet of surface on *one side* only. This battery, when fully charged, will perfectly fuse into red hot balls 30 feet of iron wire in one length; such wire being $\frac{1}{270}$ of an inch in diameter. When this battery is connected with 3,000 feet of exploring wire, during a thunder-storm it is charged fully and instantaneously, and of course as quickly discharged. As I am fearful of destroying my jars, I connect the two opposite coatings of the battery with brass balls one inch in diameter, and placed at such distances from each other as to cause a discharge when the battery receives three-fourths of its charge. When the middle of a thunder-cloud is overhead a crashing stream of discharges takes place between the balls, the effect of which must be witnessed to be conceived.

"As the cloud passes onward, the opposite portions of the zones which first affected the wire come into play, and the effect is weakened with each successive pair till all dies away, and not enough electricity remains in the atmosphere to affect a gold-leaf electrometer. I have remarked that the air is remarkably free of electricity, at least more so than usual, both before and after the passage of one of these clouds. Sometimes a little previous to a storm, the gold leaves connected with the conductor will for many hours open and shut rapidly, as if they were panting, evidently shewing a great electrical disturbance.

"It is known to electricians that if an insulated plate, composed of a perfect or of an imperfect conductor, be electrified, the electricity communicated will radiate from the centre to the circumference, *increasing* in force as the squares of the distance from the centre; whereas in a thunder-cloud the reverse takes place, as its power diminishes from the centre to the circumference. First a nucleus appears to be formed—say of positive

electricity—embracing a large portion of the centre of the cloud, round which is a negative zone of equal power with the former; then follow the other zones in pairs, diminishing in power to the edge of the cloud. *Directly below this cloud,* according to the laws of inductive electricity, must exist, on the surface of the earth, a nucleus of opposite or negative electricity, with its corresponding zone of positive, and with other zones of electrified surface corresponding in number to those of the cloud above, although each is oppositely electrified. A discharge of the positive nucleus above into that of the negative nucleus below, is commonly that which occurs where a flash of lightning is seen; or from the positive below to that of the negative above, as the case may be; and this discharge may take place according to the laws of electricity through any or all of the surrounding zones, *without influencing their respective electricities,* otherwise than by weakening their force by the removal of a portion of the electric fluid from the central nucleus above to that below; every successive flash from the cloud to the earth, or from the earth to the cloud, weakening the charge of the plate of air, of which the cloud and the earth form the two opposite coatings."*

It would appear, therefore, from Mr. Crosse's observations of the phenomena of a thunder-storm, that the cloud between which and the earth discharges occur is electrified in concentric rings, each one becoming less intensely charged towards the extremity. As each ring or zone must of course become enlarged as its distance from the centre increases, the quantity of electricity in each zone may probably be assumed to be equal; though to this point Mr. Crosse's observations do not extend. Though the electricity of the atmosphere is in all essential particulars the same as the electricity excited by the machine, the condition in which it exists in a thunder-cloud is different from any that can be artificially produced, in consequence of the magnitude of the scale on which nature operates. The strongest spark emitted from the most powerful electrical machine does not exceed two or three feet in length; and when numbers of such sparks are accumulated in an electrical battery, so as to imitate, in a feeble manner, the destructive effects of lightning, the charge, when spread over the surface of the glass, will not force its way through more than two inches of resisting air. A discharge between the clouds and the earth will sometimes occur when the thunder-cloud cannot be less than 300 feet above the object struck by lightning; though the resistance of the intermediate space is no doubt greatly diminished by the moist atmosphere and by rain. The electricity in the clouds immediately before the discharge must consequently be of a very high degree of intensity; and there is ample evidence in the destruction of imperfectly conducting bodies of the immense quantity of electricity concentrated in a flash of lightning.

A long spark from a powerful electrical machine, severed and *zig-zagged* by the resistance of the air, nearly resembles in form a flash of forked lightning; and in speculating on the mode of the action of lightning, the spark of an electrical machine, in consequence of its greater intensity, may be taken as bearing a closer analogy to it than the disruptive discharge of an electrical battery. In considering, therefore, the disputed question of the best mode of protection from lightning, and the effects of lateral dis-

* Noad's Lectures on Electricity.

charge, we are more likely to arrive at safe conclusions if the character of the discharge from the prime conductor be examined, rather than the more powerful, though less concentrated, discharge of the battery.

The question in dispute in reference to the lateral discharge is, whether a lightning-conductor, allowed to be of proper thickness, will conduct a disruptive discharge safely from the clouds without danger of injury from the passage of the electricity in other than the direct course. It is adduced, as an illustration that there is danger in lightning-conductors, that when a discharge from an electrical machine is conducted to the earth by a very efficient wire, sparks may nevertheless be drawn from the wire at any part of its course, though sparks cannot be drawn when the conducting body is connected with the wire itself. It has hence been inferred, that to render a lightning-conductor perfectly safe, all conducting bodies near it should have a metallic connexion with the rod. It appears, however, that the simplest mode of viewing the subject is to regard every discharge of lightning as distributed among *all* conducting bodies in the vicinity, forcing its way through every course open to it in quantities proportioned to the facilities offered for its passage. According to this view, we must consider that in every flash of lightning there is not only a lateral discharge, but what may be termed a *distributive discharge* within a definite range.

The quantity of electricity that finds its way to the earth through these multifarious channels will be proportionate to their relative conducting powers. Suppose, for example, that a wire were joined to the lightning-conductor, and continued uninterruptedly to the earth; as much of the electric fluid would be conducted through that wire, in proportion to its thickness, as through the main conductor. If, however, the continuity of the wire were interrupted, the resistance occasioned by the imperfect connexion would very materially diminish the quantity of electricity transmitted, though some portion would still pass through the divided wire. We may conceive that, in the same manner, every other substance, however imperfectly it conducts, transmits some portion, though it may be inappreciably small, of the infinitely divided charge.

The preceding consideration of the question is not calculated to diminish the value of lightning-conductors; but it points out the danger of dividing the discharge of lightning in such a manner as to direct a large portion of the electric fluid from its direct course. It was stated by Dr. Faraday, in evidence before the committee of the House of Commons, that a man would be safe even though leaning against the conductor of a ship when struck by lightning; nor is it probable that an appreciable quantity of electricity would pass from the continuous metal rod to find a devious and resisting course elsewhere; but if the man leaning against the conductor were at the same time to be standing on the iron cable, so as to form part of a metallic connexion with the sea in another course, there can be little doubt he would receive a shock more or less severe. The author's personal experience, as previously mentioned, enables him to speak of the distributive character of the discharge of lightning. When the electric fluid passed through his arm, that limb was sharing the discharge with many other and much better conductors of electricity; and though the sensible effect extended only from the wrist to the shoulder, a much smaller quantity of electricity must, according to the principle of distributive

discharge, have passed through his body to the support on which he was standing. A serious instance of distributive discharge of lightning occurred last summer at Paddington. A row of buildings was struck by lightning, and four men, at work *in different houses*, were killed.

There has lately been much variety introduced in the forms of lightning-conductors. In the early days of their application, electricians questioned whether the elevated portion of the rod should terminate with a metal knob or a point, or whether it should be formed of a non-conducting substance. The point, however, gained the day; as it was rightly considered better to attract the electricity silently and gradually than to trust to the rod only for conducting a disruptive discharge. The notion of tipping the end with a non-conductor was simply absurd. Those who thus attempted to keep off lightning might with equal reason have erected a glass rod instead of a metal one. The opposite principle is now so generally adopted that, with a view to increase the silent attraction of atmospheric electricity to lightning-conductors, it is customary to add several branching points. It may be questioned, however, whether any advantage is gained by more than a single point.

A recent invention, to which her Majesty's letters patent have been granted, exhibits a curious misconception of the true properties of lightning-conductors. The patentee terminates his lightning-conductors with a great number of *magnetised steel points*, conceiving, no doubt, that as there is an intimate connexion between electricity and magnetism, the magnetism of the points would add greatly to their attractive power. As iron and steel do not conduct electricity so readily as copper, the latter metal is the best for the purpose; and it is employed by Sir W. Snow Harris in his system of protecting ships from lightning. The greater expense of copper prevents its adoption on buildings, and a proportionally thicker rod of iron coated with zinc, or, as it is commonly called, "galvanised," answers the purpose very efficiently.

Buildings to which lightning-conductors are attached, elevated several feet above the highest point, are in little danger during a thunder-storm. In houses not so protected, the place of greatest safety is an under-ground cellar. Those who are alarmed, and yet do not like to descend into the cellar, will do well to lie down on a sofa near the middle of the room, taking care to avoid the proximity of suspended chandeliers, or any other interrupted metallic body. Persons who are exposed out of doors in a thunder-storm should avoid taking shelter under trees; for though they possess sufficient conducting power to attract lightning, they are not such good conductors as the fluids of the human body, and the electricity will consequently take its course to the earth through the better conductor.

In the mountain valleys of Savoy, application has been made of pointed rods to draw the electricity silently from the atmosphere for the purpose of protecting the vineyards from the destructive effects of hail, which frequently accompanies a thunder-storm. These conductors of electricity, termed *paragrêles*, have been found to answer very effectively.

There is much variance of opinion respecting the requisite thickness of lightning-conductors. A French commission appointed to determine the question reported that a rod of iron seven-tenths of an inch square is quite sufficient under all circumstances. In the lighthouses and public buildings in this country, rods of copper three-quarters of an inch wide

and about a quarter of an inch thick are employed, and as copper conducts electricity seven times better than iron, these conductors are consequently much more efficient than those recommended for adoption in France; yet several lighthouses so protected were damaged during the thunder-storms of last autumn, and Eddystone lighthouse was considerably damaged by lightning in January last. As the resistance of a metal rod to the conduction of electricity is greatly increased by its length, a much thinner conductor is sufficient for a dwelling-house than is required for a lofty building.

Wires will sometimes serve to conduct lightning safely even when so thin as to be melted by its transmission. A remarkable instance of this kind is noticed in the following unpublished letter of Franklin's, which will be read with considerable interest.*

Philadelphia, March 1, 1755.

SIR,—I am but just returned from a long journey, after near six months' absence, and find your favour of September 29, by which have the agreeable advice that you expect to be able to remit me something in Smith's affairs very soon.

As to the thickness of wire necessary or sufficient to conduct a large quantity of lightning, concerning which you desire my sentiments, you will find something on that head in pages 124 and 125 of the enclosed pamphlet, which please to accept. And I may add, that in my late journey I saw an instance of a very great quantity of lightning conducted by a wire no bigger than a common knitting-needle.

It was at Newbury, in New England, where the spire of the church-steeple, being seventy foot in height above the belfry, was split all to pieces and thrown about the street in fragments; from the bell down to the clock, placed in the steeple twenty foot below the bell, there was the small wire above mentioned, which communicated the motion of the clock to the hammer, striking the hour on the bell.

As far as the wire extended no part of the steeple was hurt by lightning, nor below the clock as far as the pendulum-rod reached, but from the end of the rod downwards, the lightning rent the steeple surprisingly. The pendulum-rod was about the thickness of a small tobacco-pipe stem, and conducted the whole without damage to its own substance, except that the end where the lightning was accumulated it appeared melted, as much as made a small drop. But the clock-wire was blown all to smoke, and smutted the wall by which it passed in a broad small black track, and also the ceiling under which it was carried horizontally. No more of it was left than about an inch and half next the tail of the hammer, and as much joining to the clock.

Yet this is observable, that though it was so small as not to be sufficient to conduct the quantity with safety to its own substance, yet it did conduct it so as to secure all that part of the building. Excuse this scrawl, which I have not time to copy fair.

I am, with much respect, Sir,
Your very humble servant,
B. FRANKLIN.

* We are indebted to the kindness of Charles Reed, Esq., F.S.A., for this letter, from his collection of manuscripts.

P.S. I have just been reading a similar instance taken from the *Journal des Savans* for 1676, page 113, viz :—

"En 1676, le tonnerre écrasa le clocher de l'abbaye de Saint Medard de Soissons; la foudre se porta à une grande distance le long des fils d'archal qui communiquoient à l'horloge ; elle fondit ces cordes métalliques sans faire d'autres désordres dans tout le trajet."

To Mr. James Birkit, Merchant, Antigua,
Per Capt. Snook, J. D. C.

The continuousdischarges of the electric fluid during a thunder-storm occur more frequently from cloud to cloud than between the clouds and the earth. These discharges of what are called "sheet-lightning" may often be observed at intervals of only a few seconds apart, and occurring with that rapidity for some hours, varied from time to time by discharges between the clouds and the earth. During a thunder-storm in August last, we noticed a continuous flashing among the clouds, some of the lightning being of the most vivid kind, and darting horizontally like a ball of fire across a considerable expanse of the horizon.

Several causes have been assigned for the electrical condition of the clouds. The simplest hypothesis appears to be that founded on the *plus* and *minus* theory of Franklin, which well explains the varying circumstances of the accumulations of electricity in the atmosphere, and of its frequent changes from positive to negative. The fact that the natural capacity of a body for electricity varies with changes in the extent of its surface has been already noticed. The capacity of steam and vapour for electricity, therefore, very greatly exceeds that of the water from which the steam is evaporated. Thus, when evaporation takes place from the earth, the vapour is combined with a vast quantity of electricity in a latent state. The condensation of the vapour into clouds diminishes its capacity, and a quantity of electricity is consequently set free, surrounding the particles of mist. As the mist collects into drops, a further amount of electricity is liberated, and the intensity of its condition is increased, though the actual quantity of electric fluid remains the same. On the other hand, when a cloud "melts into air," the capacity of the invisible vapour is greatly enlarged, and it absorbs the free electricity which was previously contained in the cloud. The changes continually taking place in the electrical condition of the clouds may thus be accounted for by the continual changes of state in the condensed vapour.

That the conversion of water into steam excites electricity during the enlargement of its volume may be readily proved. If a metal cup containing water be placed on the top of an electrometer, and a hot cinder be dropped into it, the sudden generation of steam will immediately cause the gold leaves of the electrometer to diverge. The water by increasing in volume has its capacity for electricity increased, and absorbs it from all surrounding bodies, leaving the electrometer in a negative state.

During evaporation from the surface of the earth, the electrical condition of the vapour may be modified considerably by the comparative rapidity or slowness of the process; but it may be assumed that under all circumstances the vapour obtains, at the time of its formation, the quantity of electricity natural to its state of density; and that it does not become

actively electrical by being *plus* or *minus* until it undergoes a change of state when it has risen in the air and become insulated from the earth.

When the clouds are in such a highly electrical state as to cause a discharge between them and the earth through a large intervening space of the resisting air, it might be imagined that one such discharge would neutralise the condition of the clouds, and that the thunder-storm would be ended. But it must be borne in mind that the condensed vapour of the clouds is a very imperfect conductor of electricity, and that one cloud, or a portion of a cloud, may have its electricity discharged, whilst another adjoining cloud remains fully charged; in the same manner that an excited rod of glass emits a succession of discharges to a conducting body brought to different points of its surface. Thus when the electricity of one cloud is discharged whilst the surrounding clouds remain in a highly electrical state, a constant effort is made to restore the equilibrium, and discharges from cloud to cloud, called sheet-lightning, are the consequence.

The reverberating sound of thunder is produced by the devious course of lightning through the resisting air. The amount of such resistance cannot well be calculated, but as the resistance of the air to the motion of a musket-ball when propelled at the rate of 1600 feet in a second is equal to twenty pounds on the square inch, or to 120 times the weight of the ball, some notion may be formed of the immense resistance encountered by the electric fluid in its instantaneous passage through the air. The first peal of thunder heard arises from the concussion of the air at the nearest point; therefore, assuming the direction of a flash of lightning to be from the clouds to the earth, the thunder will be first heard from the part where the lightning strikes the ground. The subsequent successive reverberations are occasioned by the comparatively slow progress of sound; those rumblings of thunder last heard being, in fact, caused by the first impulsive action of lightning on the air.

We have heard it remarked by Faraday as a curious error of artists in their representations of thunder-storms, that they make the lightning *pointed* towards the earth. Now, if it were possible to trace the course of a flash of lightning by the eye, the part near the clouds, being the more distant, would appear to be much more pointed than that part which would be seen approaching the earth.

The phenomena of the aurora borealis and of "falling stars" are attributable directly to atmospheric electricity. In the upper regions of the atmosphere electricity is readily conducted, and flashes of electric light are transmitted through the highly rarefied air with little resistance. The experiment of sending flashes of light through an exhausted receiver exemplifies, with considerable accuracy, the phenomenon of the aurora, but there are other circumstances connected with it, in reference to the sources of electrical excitement and the conditions in which the electricity is developed, that yet remain undetermined.

CHAPTER X.

ELECTRICITY FROM HIGH-PRESSURE STEAM.

Steam, an abundant source of electrical excitement—Hydro-Electrical Machine—State of the electricity excited by it—Combination of quantity and intensity—Friction of water the cause of excitement—Faraday's experiments on High-Pressure Steam.

THE excitement of electricity by the emission of high-pressure steam is the most recently discovered means of disturbing the electrical equilibrium; and it affords a more abundant supply of electricity of great intensity than any other artificial source.

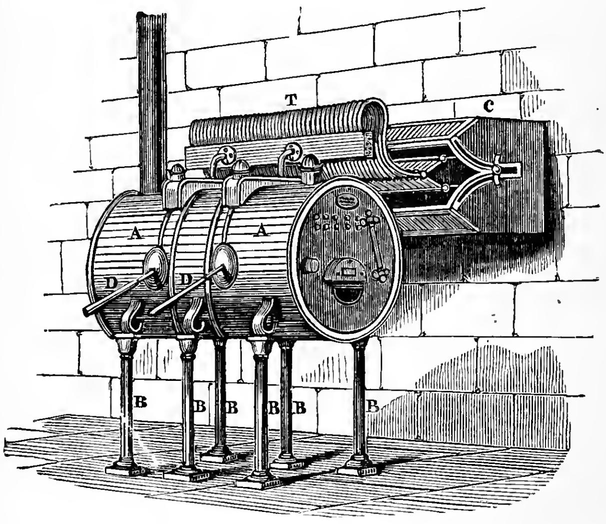


fig 37.

The effect is not fully developed unless the steam be raised to a pressure of 50 lbs. on the square inch. The apparatus constructed for exhibition at the Polytechnic Institution is the largest machine of the kind yet made. The boiler A A, fig. 37, is constructed on the same principle as the boilers of locomotive steam-engines; being perforated longitudinally by tubes, through which the draught of the furnace passes. These tubes serve the double purpose of increasing the generation of steam and of strengthening the boiler. The length of the boiler is six feet six inches; its diameter, including the furnace, which is in the centre, is three feet six inches. There are forty-six bent tubes, T, at the top for the escape of the steam. These tubes are made of iron, but the jets through which the steam issues are formed of partridge wood; that material having been found by

experience to give the best results. In front of the jets there are several rows of metallic points, for the purpose of conducting the electricity, as quickly as it is excited, to the earth, and thus to prevent its return to the boiler from which the sparks are taken. The boiler is insulated from the ground by six stout glass pillars, B B B, about three feet high, on which the apparatus rests.

The pressure of steam commonly used in experimenting with this apparatus is 60 lbs. to the square inch. When in full operation, with steam issuing from the 46 jets, the torrents of electricity evolved bear some resemblance to those described by Mr. Crosse as having poured forth from his exploring wire during a thunder-storm. The electricity excited combines quantity with intensity. Though the sparks emitted are not so long as those from the large plate-electrical machine in the Polytechnic Institution, they are more dense, and approximate to the character of the spark from the discharge of an electrical battery. The length of the sparks that may be taken from the boiler is about fourteen inches, and at the distance of six inches there is a rapid flow of electrical discharges too quick to be counted. The large battery of the institution, comprising 84 feet of coated surface, is fully charged in eight seconds; though requiring at least fifty seconds to be charged by the plate-electrical machine in its best action.

The sparks from this apparatus ignite gunpowder and inflame paper and wood shavings, and by this means also numerous effects of electro-chemical decomposition can be exhibited.

The excitement of electricity by effluent high-pressure steam appears from the experiments of Dr. Faraday and Mr. Armstrong to be caused by the friction of condensed water against the jet from which the steam issues. It was found that when the jet and the pipe leading to it were heated, so as to prevent the condensation of the steam before it issued forth, scarcely any electrical effects were produced; and that they were increased by lengthening the pipe, so as to cause greater condensation. It is for this object that the emission pipes of the apparatus at the Polytechnic Institution are bent so as to allow the water to collect near the apertures.

There are several additional facts tending to confirm the opinion that friction is the cause of the excitement of the electricity thus produced, and not evaporation or mere change of density in the steam. In Faraday's experiments no electricity was excited when the safety-valve was opened wide, and the steam escaped without friction, but when it was allowed to impinge on a cone, electrical effects were directly manifested. Changes in the substance of the jet, or of the material of the cone on which the issuing steam impinged, greatly affected not only the quantity of electricity excited, but its character. When distilled water was employed, the boiler was in nearly all cases charged with negative electricity, and the issuing steam was positive; but by the introduction of oil of turpentine into the jet the boiler became strongly positive and the steam negative. In all cases, however, the issuing steam and the insulated boiler were found to be in opposite states of electricity.

In the experiments conducted by Faraday with a small apparatus, the pressure of steam never exceeded thirteen inches of mercury, or about six pounds to the square inch, and generally it was not more than five pounds;

therefore the effects were very feeble compared with those of the hydro-electrical machine at the Polytechnic Institution. In some respects, however, this more feeble excitation of electricity was of advantage, as it afforded the opportunity of detecting changes of state that would not probably have been noticed under the action of much stronger pressure. It was found, for instance, that electrical effects could only be obtained when distilled water was employed ; for the mixture of any saline salts, or of any soluble substance that improved the conducting power of the fluid, prevented its acting as an electric with a low degree of friction. One of the many curious results derived from these experiments is, that water may claim to rank among the first of the positive electrics ; and Faraday conjectures that further investigation will place it at the head of all substances as a positive electric ; for even glass became negatively electrical when exposed to friction of the emitted steam of pure water.

With a view to prove still more conclusively that the electricity excited by emission is due to friction and not to expansion, the experiments were repeated with compressed air substituted for steam. Under these circumstances electricity was excited when moisture was supplied to the jet, but when the air and the emission pipe were dry, no electrical effects could be detected.

The excitement of electricity by effluent steam affords a striking illustration of one of the numerous ways in which electrical agency operates without our consciousness of its presence. An ordinary locomotive engine generates during every minute of its onward course a force sufficient to destroy instantaneously all the passengers it propels. This force, however, is dissipated as soon as it is created, and it was only by accident that its existence became known. It is the same with nearly all the chemical changes that are taking place around us. Even the burning of a candle, there is reason to believe, puts in action an amount of electricity greater than that of a thunder-cloud, though no means have yet been discovered of preventing the force from being dissipated unperceived. In other chemical actions, however, less energetic than combustion, the accompanying electricity can not only be detected, but it is developed in quantities, compared with which the excitement of it by friction is altogether insignificant. The consideration of the phenomena of the electricity excited by chemical agency, to which we are about to direct attention, constitutes, indeed, the most important practical branch of electric science.

CHAPTER XI.

EXCITEMENT OF VOLTAIC ELECTRICITY.

Excitement of electricity by metallic contact and by chemical action—Mutual influences of chemical action and electricity—Simple Voltaic circle—Construction of the Voltaic pile—Identity of Voltaic and frictional electricity—Volta's *couronne de tasses*—Conditions requisite for the excitement of Voltaic electricity—Solid and Liquid elements of the battery—Their actions and re-actions—Faraday's hypothesis of conduction through fluids—Resistance to the Voltaic current—Ohm's formula—Local action in batteries—Intensity and quantity of electricity considered—Their correspondence and difference.

The discovery by Galvani that muscular contractions are produced by the contact of dissimilar metals, and the rapid successive additions to that discovery by Volta and others, have been already noticed in our introductory sketch of the history of electricity. We shall now proceed to explain more particularly the character and the actions of the force thus generated by chemical action.

The simplest manifestation of the excitement of a peculiar force by the contact of metals is obtained by placing a piece of zinc under the tongue, and a piece of silver upon it, and then allowing the metals to touch. Before contact, no sensation is perceived beyond the mere pressure of the two hard substances against the tongue; but the instant that contact is made it is accompanied by a strong metallic taste, which continues without intermission. The same sensation will be perceived if, whilst the two metals are kept separated, a metallic connexion be made between them by touching each with a piece of copper wire.

When a plate of zinc is immersed in diluted sulphuric acid, chemical action immediately commences. The oxygen of the water combines with the metal, and the hydrogen is liberated and exhibits itself in a copious discharge of bubbles of gas; the water being decomposed by the superior affinity of its oxygen for the zinc. The decomposition continues until the sulphuric acid, which greatly facilitates the action, is exhausted by the combination of the sulphur with the zinc, forming, in connexion with the oxygen portion of the decomposed particles of water, soluble sulphate of zinc. This is the ordinary chemical action which takes place during the generation of hydrogen gas for experimental purposes; the quantity of hydrogen gas evolved being exactly proportionate to the oxygen with which it was previously combined to form water.

When the surface of the zinc plate is well amalgamated with mercury, the continuous decomposition of the water is prevented. Those particles of fluid only in immediate contact with the metal are decomposed. The hydrogen gas collects in minute bubbles over the surface of the plate; but they do not attain sufficient size to detach themselves from the metal, and the plate consequently becomes coated with innumerable minute bubbles of hydrogen gas. This gaseous coating protects the metal from being further acted on by the acidulated water; and it would thus remain in the liquid, unchanged, for a length of time.

A piece of sheet copper may be immersed in the same vessel without causing any alteration in the state of things, so long as the metals are kept apart. Bring the copper gradually closer to the zinc until scarcely any perceptible space intervenes, still there will be no action; but the instant that the metals touch, a brisk action commences. The bubbles on the surface of the zinc are transferred to the copper, and rise rapidly to the top of the fluid; these are followed by continuous successions of bubbles of gas, all rising from the copper surface, as if the chemical action were taking place with that metal. It is the zinc, however, that is alone attacked, and being deprived of its protecting coating of bubbles, it continues to be converted into sulphate of zinc, until, as in the previous case, the free sulphuric acid is exhausted.

It is not necessary for the production of this effect that the metals should touch in the fluid. If the lower parts only of the plates be immersed, and the upper ends are brought together, the formation of bubbles proceeds quite as briskly as when the metals are in contact in the liquid. Neither is it requisite that the copper and zinc should be immediately connected. If the lower ends of a copper and of a zinc plate be immersed, and the parts out of the fluid be connected with a wire, as in the annexed diagram, the evolution of bubbles from the copper surface will continue, though not so rapidly as before; the diminution in the action arising from the resistance which the wire offers to the passage of the stimulating force.

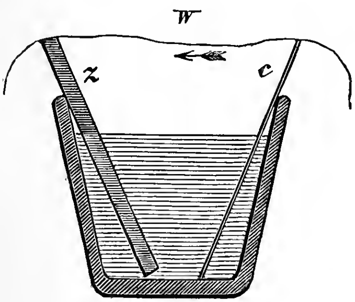


fig. 38.

Preserving the order of arrangement shewn in the figure, let the sizes of the plates be enlarged till the extent of surface immersed amounts to about fifty square inches. The evolution of gas from the larger surfaces will be greater than before, but not in proportion to their increased extent; for if the thickness of the connecting wire W do not correspond with the increased capacity of the plates, the resistance it offers will diminish the effect. Let the wire be reduced to the size of a hair, and another remarkable phenomenon will be observed. The force is then much greater than can be freely transmitted through that thin wire, and it is developed in the form of heat. The wire will become red hot, and, if the action be energetic, will even be melted in the act of transmitting from plate to plate the peculiar power by means of which water is decomposed.

The phenomena of chemical action hitherto noticed bear but little apparent relation to those of electricity. The power of decomposing water and of melting metals is, indeed, common to both; but it is exhibited in such different forms, that no argument in favour of the identity of the forces could be founded on those phenomena alone. Volta's pile, however, affords the means of assimilating the force thus evolved very closely to that of electricity.

If, instead of immersing the zinc and copper plates in a vessel containing acidulated water, a piece of cloth soaked in the liquid be inter-

posed between the metals, the effect will be nearly the same. The acidulated water contained in the cloth acts on the surface of the zinc when a metallic connexion is made with it and the copper, and similar results may be thus attained, though somewhat diminished in effect.

This arrangement presented a ready means of increasing the series of plates to augment the action of a single pair, of which Volta availed himself. He constructed a pile consisting of a series of zinc and of silver discs with moistened cloth interposed between each. He commenced with a zinc disc, upon that he placed a silver coin of the same size, on that a circular piece of cloth rather less than the metal discs, having previously soaked it in water slightly acidulated. On the cloth was laid another disc of zinc, then silver, and again cloth, and so on in succession until a pile of fifty series of alternate metal discs and moistened cloths was formed, as represented in fig. 39. To prevent the discs from falling, they were supported by vertical wooden pillars, and a weight was placed on the top to keep them pressed together.

When the uppermost and lowest of the plates in such an arrangement are touched with moistened fingers, a very decided shock is perceived, exactly resembling that from a Leyden jar feebly charged. The shock is, however, different from that of a Leyden jar in the continuity of its effect, for similar shocks are continued in rapid succession as long as the connexion between the plates, through the hand, is maintained. This physiological effect presents a clear analogy to the shock of the Leyden jar, and different as is the manner of its excitement, and different also as are many of the manifestations of the chemical agent, the accumulation of the force in the Voltaic pile pointed out at once its identity with electricity. Subsequent investigations, more especially the experimental researches of Faraday, have established this identity in almost every particular.

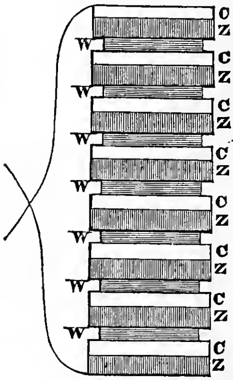


fig. 39.

The action of the Voltaic pile gradually diminishes from the time it is first put together, until at length the effect appears to cease. This diminution of power is more rapid in proportion to the energy given to the pile in the first instance by the larger quantity of acid mixed with the water. To restore the original energy, it is necessary to decompose the pile, to clean the zinc and copper discs, and to moisten the cloths again. Such an apparatus is therefore attended with much trouble. To obviate it, Volta contrived another arrangement, which he called *à couronne de tasses*. He connected a piece of zinc to a piece of copper by soldering to them a short length of bent copper wire. Having procured a number of such connected plates, he put them into a row of glasses containing acidulated water, taking care so to dispose them that the zinc and the copper connected together should be in separate glasses, in the manner represented in fig. 40.

To the copper plate in glass 1, a wire is attached to serve as a conductor for forming connexion. In the same glass there is a zinc plate connected with the copper immersed in glass 2. In this manner each

glass contains a zinc and copper plate connected by a wire, which are kept apart in the fluid, and the series may be continued to any extent. By bringing the wire attached to the first plate in connexion with a similar wire soldered to the zinc plate in the last glass of the series, the action immediately commences, and it is more or less intense according to the number of plates. This arrangement is, in many respects, very superior

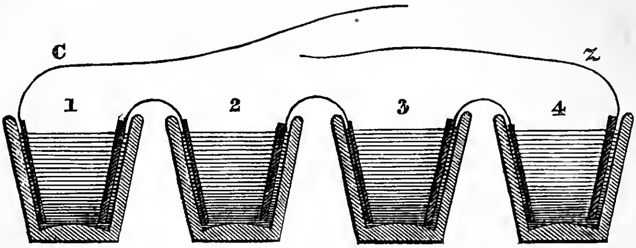


fig. 40.

to the pile. A much larger quantity of fluid can be brought to act on each plate, consequently the effect does not so rapidly diminish; the plates can be readily removed when the apparatus is not wanted, and the acidulated water may remain ready for the immersion of the plates when experiments are renewed.

The arrangement *à couronne de tasses* as invented by Volta continues, with some modifications for convenience in use, to form the voltaic battery that is most generally employed. A series of this kind, consisting of 100 plates of copper and zinc four inches square, will generate electricity in sufficient quantity to exhibit in a powerful manner most of the phenomena of frictional electricity. It is desirable, however, before noticing more particularly the phenomena of the voltaic battery, that we should examine the *rationale* of its action.

Reverting to the arrangement of a single pair of plates (fig 38), let us consider the conditions necessary for the excitement of electricity by chemical action. We observe two metals employed, one of which has a much stronger affinity to oxygen than the other. This dissimilarity in the chemical affinities of the metals will be found in all similar arrangements to be essentially necessary for the excitement of electricity; and the quantity generated will be great or small according to the degree of dissimilarity of the metals in their relations to oxygen.

The metals that excite electricity by their mutual actions are ranged in the following order; those placed first acting in reference to those beneath as copper does to zinc.

Platinum.	Mercury.	Tin.
Gold.	Copper.	Iron.
Silver.	Lead.	Zinc.

Any two of the foregoing series will constitute what is termed a voltaic circuit. Thus zinc will excite voltaic action in combination with iron; iron will take the place of zinc when combined with tin; and tin will take the place of iron when combined with copper. The energies of these

combinations increase as the metals are more distant from each other in the scale, the most powerful practical combination being zinc and platinum, the most incorrodible of all metals.

Though two plates are necessary in such an arrangement, only one of them is active in the excitement of electricity, the other plate serving merely as a conductor to collect the force generated. A metal plate is generally used for that purpose, because metals conduct electricity much better than other substances exposing an equal surface to the fluids in which they are immersed; but other conductors may be used, and when a proportionately larger surface is exposed to compensate for inferior conducting power, they answer as well, and in some instances even better than metal plates. Charcoal has been employed as one of the elements of a voltaic battery; but the most advantageous is graphite, a very hard substance that is found encrusted within gas retorts. As it is altogether impervious to the action of acids, it may be ranked even above platinum in the scale of non-oxidizable bodies; and though not so good a conductor as that metal, its finely granulated or crystallised texture exposes so large a surface to the fluid, that the conducting power is practically nearly equal to it.

We have hitherto considered only the solid elements of the voltaic battery. They form, indeed, the most conspicuous parts of the arrangement, but they serve merely as the intermediate agents for the development of the electric force. The chemical action that gives rise to the excitement of electricity takes place during the decomposition of the liquid in which the plates are immersed. It is essential, therefore, to the formation of an active voltaic arrangement, that the liquid employed should be capable of being decomposed. Water is most conveniently applicable for the purpose. Its elements, oxygen and hydrogen, are separated by the superior affinity of the oxygen for the zinc; especially when that affinity is heightened by the connexion of the zinc with an incorrodible metal, to which the hydrogen gas of the decomposed molecules of water is attracted. Whether the electricity evolved be the cause or merely the effect of chemical action is at present unknown. In whichever way the phenomenon be regarded, the electricity appears to be excited at the surface of the active plate, thence to be transferred to the conducting plate, and back again through the connecting wire to the zinc, forming what is termed an electric current.*

Water being a very imperfect conductor, it offers so much resistance to the passage of the electric current that a very small quantity of voltaic electricity can be excited when water alone is employed; especially when

* The terms 'electric fluid' and 'electric current,' which are frequently employed in describing electrical phenomena, are calculated to mislead the student into the supposition that electricity is known to be a fluid, and that it flows in a rapid stream along the wires. Such terms, it should be understood, are founded merely on an assumed analogy of the electric force to fluid bodies. The nature of that force is unknown, and whether its transmission be in the form of a current, or by vibrations, or by any other means, is undetermined. At the meeting of the British Association for the Advancement of Science at Swansea, a discussion arose on the nature of electricity, and Dr. Faraday was called on to give his opinion. He then said, "There was a time when I thought I knew something about the matter; but the longer I live, and the more carefully I study the subject, the more convinced I am of my total ignorance of the nature of electricity." After such an avowal from the most eminent electrician of the age, it is almost useless to say that any terms which seem to designate the form of electricity are merely to be considered as convenient conventional expressions.

the plates are at a considerable distance apart. By the addition of an acid or a neutral salt to the water, the conducting power is greatly increased, and the excitement is augmented in a corresponding degree. It is a disputed point whether the increased action from the addition of acids arises from the improved conducting power alone, or whether it is to be attributed also to the increased affinity of the oxygen to the zinc. The effect is most probably owing to the joint effort of the two forces.

In the opinion of Faraday, the conduction of electricity through liquids is accompanied by, if it be not owing to, the successive decomposition of the intervening particles. When a copper and zinc plate, for example, are connected together and immersed in diluted acid, the oxygen in the particle of liquid contiguous to the plate enters into combination with the metal, and its equivalent quantity of hydrogen is disengaged. The hydrogen is not immediately liberated, but is transferred from particle to particle of the liquid in a continuous chain till it reaches the conducting plate, where, not meeting with any more liquid particles to which it can be transferred, it is liberated in the gaseous form. The intervening particles are supposed to undergo temporary decomposition during this transfer from plate to plate, and to assume a polar condition, the oxygen and hydrogen occupying opposing places in each particle of liquid.

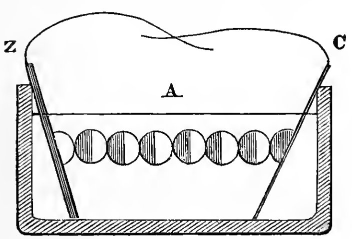


fig. 41.

The annexed diagram (fig. 41) shews, in an exaggerated form, the chain of particles of water through which the decomposing influence is supposed to be transmitted. Voltaic action having been established through water in the vessel A from the zinc plate Z to the copper plate at C, the particles between the two metals are thrown into a polar state; the oxygen of each being directed towards Z, and the hydrogen towards C. The zinc plate absorbs the oxygen of the particle nearest to it, and the liberated hydrogen combines with the oxygen of the next adjoining particle, and in this manner a continuous interchange takes place. According to this view of the conducting power of fluids, no fluid can conduct electricity unless it be capable of being decomposed; the conduction being necessarily accompanied by a train of successively decomposed particles.

All chemical action is believed to be accompanied by the development of electricity, though in only a very limited number of arrangements can it be observed. It is necessary for the sensible development of the force that the elements of bodies undergoing decomposition should be separated from each other in an imperfectly conducting medium, and be transferred in different directions. These conditions are complied with in a voltaic arrangement of a pair of plates of dissimilar metals, immersed in a decomposable fluid. The positive and negative electricities, which in ordinary chemical combinations immediately coalesce imperceptibly, are in the voltaic battery constrained to separate, and in order to reunite must pass along the conducting substances that connect the generating and the conducting plates. But even the best voltaic arrangements do not develop the whole of the electric force accompanying chemical decomposition.

The causes that obstruct the development of electricity in a current have been minutely investigated by Professor Ohm, of Nuremburgh, who has reduced them to mathematical formulæ. The free development of electricity is opposed, in the first place, by the affinity of the elements of the exciting liquid for each other, tending to resist decomposition; secondly, by the imperfect conduction of the fluid itself; and in the third place, by the resistance of the conducting wires. As the formulæ deduced by Professor Ohm from these investigations have received general acceptance among electricians, it is desirable to put them on record, and we cannot do this in a better manner than by copying the lucid explanation of them by Dr. Golding Bird.*

"E = electromotive force, equivalent to the affinity of the exciting liquid for the generating metal, and corresponding to the amount of electricity which would appear in current if all opposing causes were removed.

"R = resistance opposed to E by the contents of the cell, arising for the most part from the affinity of the elements of the exciting liquid for each other.

"r = external resistance, arising chiefly from the imperfectly conducting nature of the wires used to convey the current.

"a = active force, or the amount of electricity which really reaches the end of the conducting wire.

$$a=\frac{E}{R+r}$$

"The theoretical value of E is diminished materially in practice by the affinity of the conducting plate for the ingredient of the exciting fluid, which tends to combine with the generating plate; this affinity, however weak, is still seldom absolutely null. The mutual affinity of the separated elements of the fluid evolved at the surfaces of the plates also lessens the intensity of E.

"The internal resistance, R, varies directly with the distance, D, between the two plates, and is inversely as the area of the section, S, of the exciting liquid. Thus the real resistance is equal to the former divided by the latter, or

$$R=\frac{D}{S}$$

"r, or the external resistance, so far as it is dependent on the conducting wire, varies *inversely* as the square of the diameter of the wire, S, and directly as its length l, or

$$r=\frac{l}{S}$$

It must be remarked that the foregoing estimate of electrical force and resistances does not take into account the actual loss of electricity by the want of proper direction. The chemical action that converts any given quantity of zinc into a metallic salt develops, with the best arrangement, a given quantity of electricity. Let it be assumed that one ounce of zinc

* Elements of Natural Philosophy.

will generate an amount of electricity equivalent to 1000; that quantity will not be diminished by the resistances considered by Professor Ohm Those resistances relate exclusively to the time in which a given amount of electricity can be generated, and have no relation to actual loss of electric force. Thus, in a well-constructed voltaic apparatus no more electricity is generated than can flow in a current through the conducting wire. If the resistance to the current be increased by diminishing the thickness of the wire or by adding to its length, the action of the generating-plate is diminished in a corresponding degree, so that if only half the electricity is developed, only half the quantity of zinc is consumed; and to whatever extent the resistances are increased the ounce of zinc will, theoretically at least, produce its equivalent of electricity, though in a longer time.

In practice, however, an actual loss of electricity does generally occur, arising principally from what is called "local action" in the generating-plate. If a plate of zinc were perfectly pure and homogeneous, no chemical action would ensue when it was immersed in diluted acid. But zinc, as it is commonly procured, contains copper, iron, and other impurities which serve to set up voltaic action over its whole surface when exposed to diluted acids, which cause a rapid decomposition of the liquid. The positive and negative electricities thus generated immediately combine, and are neutralised imperceptibly, and thus so much electric force is absolutely lost. This local action is in a great measure, though not entirely, prevented by amalgamating the zinc plates with mercury: this is readily done by first dipping them in diluted sulphuric acid, and then sprinkling a few drops of mercury on the surface and rubbing them over with a cork. The effect of amalgamation is to produce a homogeneous surface, and to protect the zinc from the action of the diluted acid until the affinity of the liquid for the metal is increased by the agency of the conducting plate.

The electricity generated by a single pair of plates possesses a very low degree of intensity. The *quantity* is only limited by the size of the plates, but no increase of size alone will add to the *intensity* of the force. Thus, though a pair of large zinc and copper plates, excited by diluted sulphuric acid, will fuse any of the metals, they cannot decompose a drop of water; because in the latter case the force is not sufficiently energetic to overcome the resistance of the fluid.

To increase the intensity of the force it is necessary to form a series of conducting and generating plates on the principle of Volta's arrangement *à couronne de tasses*.

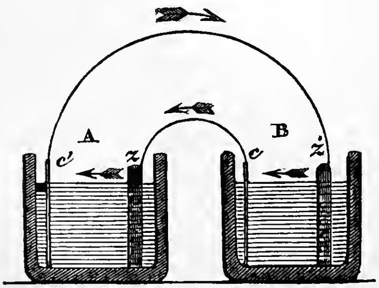


fig. 42.

It will simplify the explanation of the mode of operation to consider, in the first place, the combined action of two pairs of plates only. In fig. 42, A and B are two cells, containing diluted sulphuric acid. Into cell A an amalgamated zinc plate z is immersed; it being connected by a wire to a copper plate c in the cell B. No voltaic action would ensue between those two plates; because, being in separate

cells, the hydrogen element of the particles of water set free at the zinc plate could not be transferred to the copper. But by introducing a second pair of zinc and copper plates z' and c' into the cells, the transfer could take place, and the electric current would pass; first from z to the copper c', thence it would be conducted to the second zinc plate z' by the connecting wire, and from that through the fluid to c, and back again to the first generating plate by the wire, which completes the circuit.

In tracing the course of the electric current thus established, no notice has been taken of the action of the second zinc plate. If that be considered as inactive, except as a conductor, the quantity of electricity transmitted would be very small, owing to the resistance of the imperfectly conducting liquid. But the zinc plate in the second cell is acted on by the diluted acid equally with that in the first; and the effect is to nearly double the energy of the electric current excited by the action of the acid on the first zinc plate.

The cause of this increased action is easily intelligible, on the supposition that the electricity excited by each zinc plate is carried forward to the next in succession. Thus, for instance, a certain quantity of electricity having been excited by the zinc plate in cell A, it is transferred to the conducting plate c' in the same cell; and if a metallic connexion were made between those two plates, the electricity would be directly returned in a short circuit to z. But as there is no metallic connexion with the zinc, the electricity must pass through the wire to the surface of z', which acts as a conducting plate. The action of the acid in the second cell on the zinc excites at the same time a quantity of electricity equal to that it receives from the first plate; and this accumulated quantity being compressed within the same space is transmitted with redoubled energy through the fluid to the second conducting plate c, and thence by the wire to the first generating-plate z, to restore the electrical equilibrium.

According to this view of the action of a voltaic battery consisting of two pairs of plates, the electricity excited by the first zinc is transferred to the second, where its force is doubled by the excitement of an equal quantity, and both united traverse the wire of the return circuit. On arriving at the first zinc, half the quantity is parted with; but an equal quantity of fresh electricity is excited, and is carried on to the second zinc, where the same process is repeated; and thus the electrical equilibrium is continually disturbed and continually restored after traversing the wires that connect the plates at the extreme ends. When greater numbers of zinc and copper plates are united in a series, a similar transference of electricity from plate to plate takes place with a progressively increasing quantity and intensity of force, the action being continued as long as the series remains unbroken, or until the fluid becomes saturated with sulphate of zinc, and further chemical action is prevented.

It is necessary to state that the preceding explanation of the action of the voltaic battery differs from the view taken of it by Dr. Faraday, and after him by most other writers on the subject. In the opinion of Dr. Faraday, addition to the number of plates in a series occasions no addition to the *quantity* of electricity generated by the first pair of plates, but merely serves to give increased intensity to that quantity. Thus the most powerful effects produced by a voltaic battery consisting of 1000 pairs of plates are assumed to be caused by the same *quantity* of electricity that is

excited by a single pair only of the series: the exalted action in the former case being attributed to an increase of intensity without any addition to quantity.

This view of the nature of the action of the voltaic battery is supported by numerous ingeniously-contrived and apposite experiments;* but though fully disposed to pay the highest possible respect to so great an authority as Dr. Faraday, we think he has failed to establish the position that increased intensity is not accompanied by addition to quantity.

There are many arrangements of voltaic batteries for the development of accumulated electric force in different modes, but they all depend on the same principle. The most compact is Cruikshank's modification of the voltaic pile. Zinc and copper plates of equal size are soldered together, and then cemented into a wooden trough. Each pair of plates is fixed less than half an inch from each other, care being taken that all the zinc and copper surfaces are turned the same way. The compartments between the plates form water-tight cells, into which diluted acid, or other exciting liquid, is poured. A piece of wire is introduced at each end to complete the circuit through any substances to be subjected to the voltaic action.

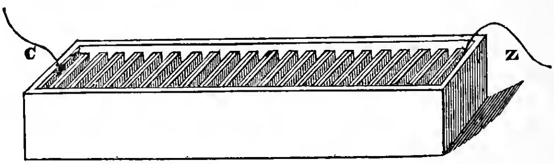


fig. 43.

A series of fifty small double plates may be cemented into a trough two feet and a half long; and two such batteries, with plates two inches square, will give a rapid succession of smart shocks, and will exhibit most of the phenomena of voltaic electricity. The disadvantages of a battery of this kind are, that the exciting liquid cannot be emptied at the end of each experiment without much trouble, and there is some difficulty in cleaning the plates when they become corroded. By emptying the cells as soon as possible and washing them with water, a battery of this construction may, however, be kept in order for a considerable time; and when voltaic electricity of high intensity and small quantity is required, a Cruikshank's battery, with plates about two inches square, is very convenient.

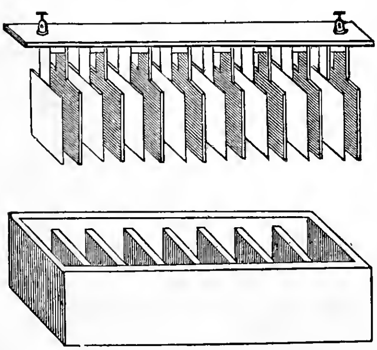


fig. 44.

An arrangement contrived by Dr. Babington affords the advantage of making the plates easily accessible for the purpose of cleaning, and also of removing them from the liquid when the experiment is ended.

* Experimental Researches.

An earthenware trough is divided by plates of the same material into water-tight compartments about two inches wide, so as to form a number of cells. Each pair of zinc and copper plates is connected by a strip of copper, instead of having their surfaces soldered directly against each other, and the zinc and the copper are placed in separate cells. This arrangement, indeed, very closely resembles that *à couronne de tasses* of Volta; but it is more compact, and as all the copper and zinc plates are attached to a piece of wood, they can be readily lifted out of the exciting liquid when not in use. This is a great convenience when a continued series of experiments is conducted at short intervals. As the earthenware trough with fixed divisions is liable to be broken, and is rather difficult to manufacture, it has been found more convenient to have the cells made separately, and to enclose them in a wooden case.

The original form of the trough has been recently very extensively used for the electric telegraph, though made of other materials than earthenware. Most of the batteries of the Electric Telegraph Company, until very recently, were constructed in wooden troughs, with partitions of slate made water-tight by means of marine glue. These, again, are being supplanted by troughs made of gutta-percha, which are very much lighter, and the cells can be more effectually prevented from leaking. The plates of these batteries are connected by strips of copper, which are bent into arches, so as to admit of each unattached pair of plates being inserted into separate cells. The zinc plates are well amalgamated, and are allowed to remain in the cells day and night, the local action being in a great measure prevented by filling each cell with fine sand, and by using sulphuric acid diluted with about twelve parts of water. A voltaic battery, with sand and diluted sulphuric acid, will continue in good action, with occasional additions of acid, for two months before the zinc plates require to be cleaned or re-amalgamated. The consumption of zinc on the numerous and extended lines of the Electric Telegraph Company is very great, the cost of battery-power amounting to nearly three thousand pounds in a single year.

Batteries in which graphite is substituted for plates of copper have been introduced by Mr. C. V. Walker in working the electric telegraphs of the South-Eastern Railway Company, and with very good results. One of these batteries of twelve pairs, of which a record was taken, was kept in daily action for ninety-seven weeks without having been washed or having the sand changed. It was supplied with about a dessert-spoonful of acid-water twenty-one times during the period it was in action, and six times with merely warm water. In one instance it did duty for seventy-seven days without having been touched.*

Dr. Wollaston contrived the arrangement shewn in fig. 45 for obtaining the greatest amount of power from a given surface of zinc. The copper plates *c c c* are doubled, so as to expose a conducting surface to both sides of the zinc plates, *b b b*. The plates are

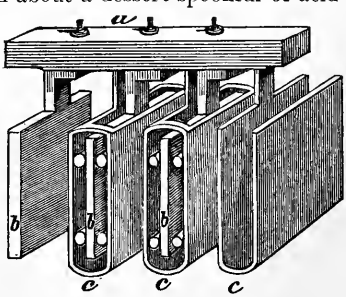


fig. 45.

* Jury Reports of the Great Exhibition.

also brought as close together as possible without actual contact. They are secured to a bar of wood, and are kept apart by pieces of cork. With a battery of this kind, consisting of a few pairs of large plates, prodigious heating power is produced, though the intensity of the electricity is too feeble to communicate a shock.

The battery invented by Professor Daniell, the action of which has been previously noticed,* is constructed on a different principle. It is found in the voltaic arrangements before mentioned, that the zinc and copper plates immersed in the same cell are liable to have their action impeded, and ultimately altogether arrested, by the transfer of zinc to the copper surface. The action of the conducting plate is also greatly retarded by the accumulation of hydrogen gas; so much so, indeed, that very frequently, after the first minute the battery has been put in action, not more than one-tenth of the original power is obtained. In Professor Daniell's battery the zinc and copper plates are kept apart by means of porous earthenware cells, or by pieces of animal membrane, which, though sufficient to prevent the passage of metallic particles, do not materially interrupt the voltaic action.

Fig. 46 shews an arrangement of a single cell of this kind: C is a copper cylindrical vessel, with a binding screw B, soldered to one edge for the purpose of holding a connecting wire. Into this copper cylinder a porous tube D, closed at the bottom, is introduced; and into the tube is placed a rod of amalgamated zinc Z, with a binding screw at the top. A solution of muriate of soda (common salt) is poured into the porous tube, and the outer copper vessel is nearly filled with a saturated solution of sulphate of copper to which a little sulphuric acid has been added.

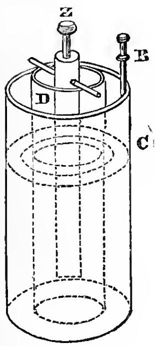


fig. 46.

When metallic connexion is made between the rod of zinc and the copper cylinder, active excitement of voltaic electricity occurs. The oxygen of the acid combines with the zinc, and the liberated hydrogen passes through the porous cell to the copper. It does not, however, escape in the form of gas, but it enters into combination with the oxygen of the sulphate of copper, and the metal, being thus deprived of its oxygen, becomes "revived," and is deposited in a metallic form on the inner surface of the cylinder. By the continued absorption of hydrogen by the sulphate, and the deposition of copper, a bright conducting surface is maintained; and this constant renewal of the conducting surface not only increases the intensity of the action, but maintains it with a steadiness that cannot be attained by any of the batteries previously described.

The constancy of action peculiar to this arrangement has obtained for it the name of the "constant battery." To maintain its constancy, the solution of sulphate of copper should, however, be preserved in a saturated state by the addition of crystals of the metallic salt; and when this precaution is observed, a Daniell's battery will continue in action for several days without much diminution of the original force. A ledge perforated with holes is generally fixed inside the copper cylinder for holding

* Page 43.

crystals of the sulphate, which gradually dissolve and keep the solution in a saturated state.

The voltaic arrangement contrived by Mr. Smee deserves special notice from its general utility. The principal differences between it and a battery of Dr. Babington's arrangement consist in the material of the conducting plate and in the mode of placing it. The conducting plate is made of silver-foil platinized; that is, a thin coat of platinum is deposited on the silver by the electrotype process. The minutely-divided particles of platinum that thus cover and adhere to the silver present a greatly-enlarged surface to liquid in which it is immersed, by which means a smaller-sized plate answers equally with a much larger one of smooth metal. Platinum also being a metal less readily oxidised than copper, the effect of the voltaic arrangement is heightened by the greater dissimilarity of the two metals. The platinized silver-foil is fixed in the centre of a wooden frame S, and two zinc plates, Z Z, well amalgamated, are attached to the upper rim of the frame by a brass clamp, which has a binding-screw connected with it. By this arrangement the zinc plates can be very readily removed and cleaned. In this respect a Smee's battery is more convenient than any other; its action also approaches a Daniell's battery in constancy. These are important advantages, which render this form of voltaic battery the best that can be used for general purposes.

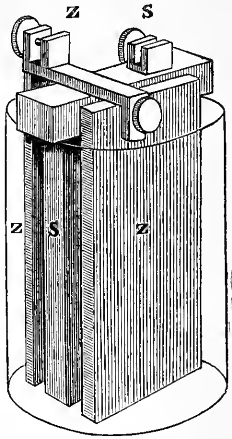


fig. 47.

The substitution of graphite for the platinized silver plates promises to be a still further improvement. With graphite conducting plates there is no occasion for the wooden frame. A single zinc plate, with a binding-screw soldered to it, occupies the central place, instead of the platinized foil, and two flat pieces of graphite may be clamped on each side; care being taken to insulate the zinc from the graphite by small strips of varnished wood. It will be observed that in this disposition of the apparatus with the graphite, the position of the exciting zinc in reference to the conducting surfaces is transposed, as well as the proportions of each to the other being reversed; a single plate of zinc being placed between two conducting surfaces instead of the conducting surface being in the centre, with a zinc plate on each side.

When a battery of great power, and occupying comparatively small space, is required, Mr. Grove's arrangement is commonly employed. The intensity of its action depends on associating two metals the most dissimilar in their chemical characters, and exposing one of them separately to the strongest exciting acid. This can only be done by using a porous cell, which keeps the zinc from the destructive action of the powerful acids employed, and to which platinum is exposed in a separate compartment. The porous cell which contains the zinc is filled with diluted sulphuric acid, in the proportion of one of acid to four of water; and the other vessel, with the platinum-foil, contains equal proportions of concentrated nitric and sulphuric acids. With a battery of this construction

consisting of fifty pairs four inches long by two wide, and which does not occupy more space than eighteen inches square, the most powerful effects may be produced; metal wires being melted into globules and dissipated in oxides, and a dazzling flame upwards of an inch long produced between charcoal points.

There are various other arrangements of voltaic batteries, but we have described nearly all those that are constructed on distinctive principles. The object in every case is to obtain from a given quantity of the exciting metal the greatest possible amount of current electricity, without allowing the power to be wasted in other ways. The consumption of a given weight of zinc cannot, by any possible combination, excite more electricity than will decompose a quantity of water equivalent to that which is decomposed by the chemical affinity of the metal for oxygen. Thus supposing two grains of water to be decomposed in the generating cell, and eight grains of zinc to be oxidized, the electricity generated during the process cannot be more than sufficient to decompose another two grains of water. The power obtained, even by the best arrangements hitherto contrived, seldom amounts to so much. By increasing the chemical action of the liquid on the generating plates, the energy of the battery is increased, but most frequently not in proportion to the consumption of zinc. By bringing the plates in the generating cells nearer together, the energy of the battery is also increased, by diminishing the intervening fluid resistance; but this may be attended with waste of power if the plates be brought too close.

Economy of construction is an important consideration when experiments are conducted on a large scale, and this must in general prevent the adoption of platinum. The use of porous cells for the purpose of preventing the deposition of zinc on the conducting plate is very advantageous, but the high price at which they are sold in this country limits their use, for after a time the pores become clogged and the vessels require to be replaced. This cannot be done in London at a cost of less than ninepence for each, though small; but the porous vessels which are used in the batteries of the electric telegraphs in India are purchased there at the rate of twenty for one halfpenny. Several contrivances have been adopted to serve the purpose of porous earthenware, such as brown-paper bags, bladder, and sail-cloth, but each has its inconvenience, and there is still wanting some cheap substitute for the earthenware vessels that are now sold at such extravagant prices.

CHAPTER XII.

PHENOMENA OF VOLTAIC ELECTRICITY.

Different conditions of Frictional and Voltaic electricity—The two poles of the battery—How to distinguish them—Mystification caused by new terms—Voltaic action immediate and continuous—Its rapid transmission exemplified—Resistance of wires to the electric current—Heating effects of the Voltaic battery—Combustion of carbon—Extraordinary physiological effects—Contrivances for giving shocks—Water-batteries—Intensity of their action—Mr. Crosse's water-battery—Cause of the intensity of water-batteries.

The power developed by a numerous series of voltaic elements, though in many respects resembling that of an electrical battery, is in several particulars dissimilar to it. The difference in the phenomena may be attributed chiefly, if not entirely, to the different degrees of intensity in which the two kinds of electricity are excited. Even when the intensity of the voltaic battery is increased by the reduplication of the power fifty times, the electricity has not sufficient energy to pass through the smallest space of resisting air in the form of a spark, nor can it exert an attractive force on light non-conducting bodies. Thus, when the electricity excited by several pairs of large plates has sufficient power to melt metals and to give a strong electric shock, the presence of electricity is not appreciable by the most delicate pith-ball electrometer. But when the elements are increased to the number of two or three thousand, as in Mr. Crosse's extraordinary water-battery, the intensity of voltaic electricity becomes so far augmented, that a spark will pass between the connecting wires before contact, and the electrometer is very sensibly affected.

The experiments of Mr. Crosse have supplied all that was wanted to shew the complete identity of the two forces, and to prove that the difference in their modes of action depends alone on the degree of intensity in which they are excited.

The electricity developed at the opposite ends of a voltaic battery appears to bear the same relation to each end as the electricity of the inside and outside of a charged Leyden jar. One end therefore is considered to be negative, and the other to be positive. If the wires from the terminating zinc and copper plates be furnished with platinum points, and inserted into a glass filled with water slightly acidulated to increase its conducting power, the fluid will be decomposed, and bubbles of hydrogen gas will rise from one wire, and bubbles of oxygen gas from the other. It will be found, on collecting the bubbles of gas in separate receivers, that the oxygen is liberated from the wire connected with the copper end of the battery, and the hydrogen from the wire connected with the zinc. In all cases of electro-chemical decomposition it is also found that the element which collects at the wire from the copper corresponds with that which collects at the positive wire of the electrical machine; hence it is inferred that the electricity evolved from the wire connected with the copper of a voltaic battery is identical with positive frictional electricity, and that the electric current proceeding from the zinc is negative. The copper and zinc ends of a voltaic battery are, therefore, commonly called

positive and negative "poles;" the word *pole* having been given to the opposite ends from the polar arrangement which, in some instances, appears to be induced by voltaic action.

It is difficult to avoid confusion in speaking of the opposite poles of a voltaic battery. This difficulty arises partly from the apparent generation of the electric force by the conducting plate, which is in reality inactive; it is partly to be attributed to the different arrangements of the zinc and copper plates in different batteries; and it is increased by the various names that have been arbitrarily given to the terminal wires.

When the electricity of a single pair of zinc and copper plates is considered, it will be observed that though the electricity is excited by the zinc, the electric current proceeds to the copper, and thence is returned by the conducting wire to the zinc. Therefore when the ends of two wires, one from the zinc and one from the copper plate, are inserted into a conducting fluid, the positive electricity will enter from the wire connected with the inactive or negative plate, and at that point the effects of positive electricity will be produced; whilst negative effects will be developed at the wire connected with the generating plate.

The contradiction apparently involved in this statement will disappear, when it is considered that the electric current excited by the zinc always tends towards the copper, which serves to conduct it back again to the generating plate; and that though the electricity appears to proceed from the copper, that metal operates only as the conductor of the current, which is assumed always to proceed from the copper to the zinc. The same effect takes place when several zinc and copper plates are combined. The wire leading from the copper end of the battery will be positive, because it is conducting the accumulated electricity on its return to the zinc end; and the other wire will be negative, because it is receiving the flow of electricity, and is consequently in a less highly charged condition.

In using a voltaic pile or a Cruikshank's battery, mistakes are likely to arise in consequence of the last zinc and copper plates not being active, but merely serving as metallic conductors. In a Cruikshank's battery, for instance, a small cell is generally left at each end without any corresponding plate opposite the last zinc and the last copper; thus, when a conducting wire is introduced at the end where the zinc is the last of the series, it is the same in effect as if the conducting wire were connected to the copper, for the last zinc plate is soldered to the copper only for uniformity, and is altogether inoperative. It would, indeed, be better if the terminal plates were cemented to the end of the trough with a binding screw attached to hold the wire, and then no confusion from that source would arise. The same observation applies to the voltaic pile, the end plates of which, to avoid mistake, should consist of a single zinc disc and a single copper disc.

We have before expressed regret at the introduction into electric science of new terms, derived from the vocabulary of a dead language, which serve to mystify, to perplex, and to mislead. The difficulty attending the clear comprehension of the right character of the two ends of the voltaic battery has been by this means increased. To call the extreme copper and zinc plates in a continued series, and the wires connected with them, the ends of the battery, expresses clearly and simply the fact, without giving sanction to any doubtful theory. But the word "end" was not deemed

sufficiently dignified. "Terminals" sounded better, but not being so generally understood it was no improvement. As the action of a voltaic battery produces in some cases a polar arrangement, the name "poles" was introduced, and the negative and positive pole of a battery have become familiar terms. The implied polarization was however objected to, and the word "electrode" has been concocted from the Greek *electron*, amber, and *odos*, a way or door, signifying the door into and out of which the electric current passes. As, however, it is questioned by Faraday himself, who sanctioned the term, whether there is any actual entrance and exit of electricity, and whether there is any *current* whatever, we may be permitted to doubt the appropriateness of the term; and even if the signification be admitted, we should much prefer its expression by an English word.

Again, the terms "positive" and "negative" were objected to, as signifying conditions of electricity, of the correctness of which many entertain doubts. With a view to improve the nomenclature, the much more objectionable terms "anode" and "cathode" have been introduced, signifying an upward and a downward way, and founded on a fancied resemblance between the direction of electric currents round the earth, and the rising and setting of the sun. The "anode" is the electrode at which the current enters, the "cathode" the electrode at which the current leaves, the decomposing fluid; the former being in fact the positive, and the latter the negative end of the battery.

When the wire from one end of a voltaic battery is connected with the wire from the opposite end, voltaic action instantly commences; and it as instantaneously ceases when the connexion is interrupted. The rapidity with which the electric circuit may be completed and broken has no ascertained limit; nor does it appear to be controlled by resistance caused by traversing miles of wire.

If a number of short lines close together be drawn with varnish or other non-conducting liquid on a smooth metallic surface, and a metal point in connexion with one of the poles of a voltaic battery be drawn rapidly over them, the electric current will pass at every minute interval between the lines, and will be interrupted each time that the lines of varnish intervene. To prove this experimentally, draw a number of straight strokes with a pen dipped in varnish on a piece of tin-foil A, fig. 48, and connect the foil with the copper end of a small voltaic battery. On to another strip of tin-foil D, connected with the zinc end of the battery by the wire Z, lay a piece of paper B, that has been soaked in a solution of diluted muriatic acid and prussiate of potass. Bend a steel wire, W, so that each end may be drawn at the same time over the moistened paper and the lines of varnish. By this arrangement the electric circuit will be completed whenever the ends of

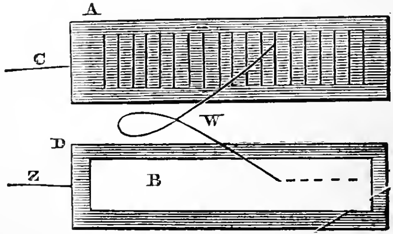


fig. 48.

the bent wire press on the foil and on the paper, and it will be broken as the point passes over the varnish. However rapidly the wire

is drawn across the varnish lines by the hand, the making and breaking of contact will be indicated on the paper by a line of blue dots. If the wire be drawn along very quickly the marks will be more faint, but the presence of electric action and the discontinuance of its action may be perceived, even when the connexion is made and broken one thousand times in a second.

Though the intensity of voltaic electricity is beyond all calculation less than that of electricity excited by friction, it nevertheless passes along a conducting wire as quickly as the discharge of a Leyden jar. In an experiment performed last autumn before the Court of Directors of the East India Company on Warley Common, a current of voltaic electricity was sent through ten thousand yards of copper wire, and a fuse at one end of the battery was ignited without any perceptible interval of time, as soon as connexion was made between the wires; the fuse having been introduced near the end of the circuit that the cause and effect might be seen to be instantaneous. In passing through a length of 2000 miles, however, a perceptible interval is observed between making connexion at one end and the resulting effect at the other.

It is a peculiar property of voltaic electricity, depending on its low degree of intensity, that it will traverse a circuit of 2000 miles rather than make a short circuit by passing through an interval of resisting air, not exceeding the hundredth part of an inch. Frictional and atmospheric electricity, on the contrary, will force a passage across a considerable interval, in preference to taking a long circuit through wire; or at least the greater portion of it will pass through the air, though some part of the charge will in all such cases traverse the wire. The resistance offered by a long thin wire to the passage of intensity electricity resembles in effect that of an imperfect conductor, and if there were no other course through which to force its way, the conduction of a charge of electricity by a long wire would occupy an appreciable time; as a Leyden jar may be discharged gradually through a wet string. When quantity is combined with intensity, the resistance offered by a thin wire occasions its fusion. Instances of this sometimes occur during thunder-storms, by the destruction of the galvanometer-coils of the electric telegraph by lightning. To protect the instruments from such accidents, advantage has been taken of the different modes of conduction by voltaic and frictional electricity, and the coil is protected by a lightning-conductor consisting of a thick piece of brass in which there is a minute interruption, quite sufficient to prevent the voltaic current from being diverted from the long circuit into the short one, but through which the lightning forces a passage in preference to encountering the resistance of the coil.

The heating effects produced by the concentration of voltaic force in a series of plates may be fully shewn by a battery consisting of ten pairs of plates in Smee's arrangement, each plate being not less than six inches square. With such a battery in good action, all the metals may be burned by attaching strips of the thinnest leaves into which they can be beaten on to a wire connected with one of its poles, and then bringing the wire from the other pole into contact. The metals will thus be deflagrated with a brilliant light, the colours of the flames differing with the metal operated on. Gold burns with a white light, tinged with blue; silver emits an emerald green light; copper burns with a greenish flame; the

flame of lead is purple; of zinc, white tinged with red; and mercury burns with a pure brilliant white light. Short lengths of thin wires are made red hot and melted when stretched between the battery connexions. The lengths that may be thus melted are proportionate to the power of the battery and the thickness of the wire.

The deflagration of metals by voltaic action, though it apparently takes place immediately on making contact, is not so instantaneous as the deflagration by frictional electricity. The difference in the rapidity of their actions may be shewn by the following experiments. Let equal short lengths of fine wire be covered with silk. First, discharge the contents of a battery of combined Leyden jars through the wire. It will be instantly deflagrated, the oxide being dissipated in powder, but the silk thread that covered it will be uninjured. Next, send a momentary current from the voltaic battery through an equal length of the covered wire by making an instantaneous connexion of the poles. The effects will now be the reverse of the former experiment; for the silk will be destroyed, whilst the wire will remain entire. In the first case the action is so rapid that the particles of metal are dissipated before the silk, a slow conductor of caloric, can be affected by the momentary presence of heat; in the second experiment, the slower action of the voltaic power has not time, during the short contact, to exert its full power and to melt the wire, though it heats it sufficiently to burn the silk.

The most brilliant of the phenomena of voltaic electricity is the light evolved between two charcoal points. To exhibit this effect a battery consisting of at least fifty pairs of copper and zinc plates four inches square is required. Two pointed pieces of graphite answer better than wood charcoal. They may be conveniently fixed to the rods of the universal discharger, each rod being connected with the opposite ends of the

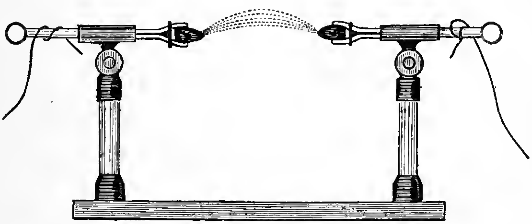


fig. 49.

voltaic battery, as shewn in fig. 49. The two points must first be brought into contact; and the electric current being thus established, the pieces of graphite, after being heated, may be gradually separated from each other, to the distance of an inch and upwards, without breaking the voltaic circuit. The space between the points is occupied by an arch of flame that nearly equals in dazzling brightness the rays of the sun.

The cause of the phenomenon is not exactly understood. The light is not occasioned by ordinary combustion, for it is equally bright in a vacuum, and may be produced, with diminished intensity, in water. It seems probable that minute particles of carbon become separated from the points, and that their incandescence, under the influence of voltaic action, causes the brilliant light. M. de la Rive has produced a voltaic arch of nearly

equal brilliancy by substituting a finely divided preparation of spongy platinum for charcoal. During the evolution of light from charcoal points there is a transfer of a minute portion of carbon from one to the other. A small hollow cone is made in the piece of charcoal connected with the positive pole of the battery, and on the point of the negatively-connected charcoal a projecting cone is deposited that exactly fits the cavity. The light is accompanied by heat sufficiently intense to fuse any of the metals.

The intimate relation subsisting between voltaic action and the nervous influence has not latterly excited so much attention as in the early days of the discovery of voltaic electricity. The extraordinary contortions of the limbs on connecting the nerves and muscles of recently killed animals with the poles of a voltaic battery, gave rise to the impression that by the agency of galvanism the vital functions might be carried on after death. This opinion has been to some extent realised by experiment. Dr. Philip succeeded in maintaining the respiration, the pulsation of the heart, and the circulation of the blood, in rabbits from which the spinal marrow and brain had been removed; and he inferred from these experiments "the identity of galvanic electricity and nervous influence."

Some remarkable experiments on the body of a recently-executed murderer are recorded by Dr. Ure, who superintended the arrangements. The experiments were conducted in the theatre of anatomy at Glasgow. The body was that of a middle-sized, athletic, and extremely muscular man. He was taken into the theatre about ten minutes after he had been cut down, his face having at the time a perfectly natural aspect, and the neck not dislocated. The voltaic battery put in requisition consisted of 270 pairs of plates four inches square. On placing one wire of the battery on the exposed spinal marrow on the neck, and the other on the sciatic near the left hip, "Every muscle of the body was immediately agitated with convulsive movements, resembling a violent shuddering from cold. The left side was most violently convulsed at each renewal of the electric contact. On moving the second wire from the hip to the heel, the knee being previously bent, the leg was thrown out with such violence as nearly to overturn one of the assistants, who in vain attempted to prevent its extension."

In another experiment, directed with the view of renewing the respiratory process, "Full, nay, laborious breathing instantly commenced. The chest heaved and fell; the belly protruded and again collapsed with the relaxed and retiring diaphragm." One of the connecting wires having then been applied to the forehead, the other to the heel, "Every muscle in his countenance was simultaneously thrown into fearful action; rage, horror, despair, anguish, and ghastly smiles united their hideous expression in the murderer's face. At this period several of the spectators were forced to leave the apartment from terror or sickness, and one gentleman fainted." Dr. Ure was of opinion that if the pulmonary organs had been excited before the spinal marrow had been wounded, the man might have been restored to life.

To produce physiological effects with the voltaic battery, intensity rather than quantity is required. To communicate an electric shock directly from the battery requires a series of fifty pairs of plates, and even then the shock is only feeble. Even with a series of one hundred pairs the intensity is scarcely sufficient to overcome the resistance of the outer

skin, without dipping the hands in acidulated water or an alkaline solution. The effect of the shock is increased when the surface of contact is enlarged by attaching small copper cylinders to the wires; for by this means the imperfect conduction of voltaic electricity through the skin is compensated by the larger surface exposed to its action; it being one of the properties of conducting bodies that a bad conductor of voltaic electricity offers no more resistance to an electric current than a good conductor, provided the size of the former be great in proportion to its degree of imperfect conduction.

A voltaic battery of six large plates, capable of fusing metals with facility, produces no sensible effect when the wires from the opposite poles are held in the hands; but when they are applied to the more delicate and sensitive substance of the tongue, a very strong and disagreeable sensation is experienced. By adding to the intensity of the current the physiological effects are greatly increased, even when the quantity of electricity generated by each pair in the series is extremely minute. A water-battery was constructed by Professor Daniell that consisted of 2100 series. The conducting surfaces were formed of pieces of copper tube, about one inch long and three-eighths of an inch in diameter, the generating surfaces being pieces of zinc wire soldered to the copper tubes, and bent so as to enter into the centre of each proximate copper tube without touching it. Small separate cups filled with pure water, into which each copper and zinc element was immersed, completed the arrangement. This Lilliputian battery of numerous elements excited a current of electricity closely approaching in intensity to that of a Leyden jar. It gave shocks, emitted sparks, affected strongly a gold-leaf electrometer, and attracted light substances.

The direct effects of this battery were almost inappreciable when applied to metals, but they could be multiplied in exactly the same manner as the effect of an electrical machine is increased. An extended coated surface of glass could be continuously charged by this water-battery, and then the *quantitive* effects were much greater. The charge was communicated to a coated surface of several square feet almost instantaneously. A succession of discharges was obtained to the same extent, but more rapidly, as when the electrical battery was charged by a powerful machine.

Though the full charge which this water-battery was capable of communicating was imparted almost instantaneously, there was an appreciable interval between each discharge of the Leyden battery sufficient to indicate that the voltaic action, though apparently immediate, consists of a succession of efforts rapidly following each other. This is particularly the case when the current has to pass through an imperfect conductor, like the human body; the force seeming to require to be accumulated till it attains sufficient energy to overcome the resistance. When metals form the circuit, the electricity passes as quickly as it is generated, and there is in that case no occasion to increase the intensity by adding to the series of plates.

A water-battery has been constructed by Mr. Crosse with much larger surfaces than those of Professor Daniell, and with the cells more carefully insulated. A particular account of it is given by Mr. Noad, who was present during many of the experiments.* It consists of 2,500 pairs of

* Lectures on Electricity.

copper and zinc cylinders, most of which are enclosed in glass jars. They are all well insulated on glass stands, and are ranged on three long tables, well protected from dust and from the light—a situation which experience has shewn Mr. Crosse to be most favourable to this peculiar form of the voltaic battery. Thirty pairs afford a slight spark sufficient to pierce the cuticle of the lip, the hand making the communication being wetted; 130 pairs open the gold leaves of the electrometer about half an inch; 250 pairs cause the gold leaves to strike the sides of the glass; 400 pairs give a very perceptible stream of electricity to the dry hand; 500 pairs occasion that part of the dry skin which is brought in contact to be slightly cauterised; 1,200 pairs give a constant small stream of electricity between two wires placed $\frac{1}{100}$th of an inch apart, such wires not having been previously brought into contact. This stream, when received by the dry hands, is exceedingly sharp and painful. A pith ball, a quarter of an inch in diameter, suspended by a silk thread, will constantly vibrate between the opposite poles. With 1,600 pairs, the stream between the two wires not previously brought into contact is very distinct; it may be kept up for many minutes, nor does it appear inclined to cease. The light between charcoal points, even with the whole series, is feeble; there is no flame, or approach to it. When the opposite poles of 2,400 pairs are connected with the inner and outer coatings of an electrical battery containing seventy-three feet of surface, a continual charge is kept up; each discharge being attended with a loud report heard at a considerable distance. Each of these discharges will pierce stout letter-paper, and fuse a considerable length of silver-leaf, which it deflagrates brilliantly, attended with loud snappings of light more than a quarter of an inch in length. Platinum wire is fused at the extremity, and the point of a penknife is soon demolished. Light substances are attracted at a distance of some inches, and repelled again.

The intensity effects of a water-battery may be considered to be consequent on the bad conducting power of that fluid. The small quantity of electricity generated by each zinc plate is transmitted from plate to plate to the end of the series, and it is prevented from returning through the liquid in the cells by non-conducting resistance. Thus, though a much less quantity of electricity is generated, it is increased by each successive plate in a greater proportionate degree than when a better exciting, and at the same time a better conducting, fluid is employed. The greater degree of intensity accumulated in a numerous series of elements makes the insulation of the cells more necessary, which is a point but little attended to in voltaic batteries of few combinations, and excited by diluted acids.

CHAPTER XIII.

SECONDARY CURRENTS.

The Voltaic current dependent on resistance—Induction of secondary currents on making and breaking contact—Induction of electricity in a separate wire—The direction of secondary currents opposite to primary—Faraday's views of the action of induced currents.

The manifestation of the presence of electricity, whether excited by friction or by chemical agency, depends, as we have previously observed, altogether on resistance to its diffusion. Were there no resisting medium there would be no development of electric force, because it would be neutralized as quickly as generated by unimpeded conduction. A glass rod cannot be excited by friction unless the air be, partially at least, dry and non-conducting; whilst, on the other hand, a metal rod may serve as an electric, if the dispersion of the electricity be prevented by insulating the metal on a glass handle, which resists the flow of the electric fluid. It is resistance, also, that in the same manner induces the manifestation of voltaic electricity. Were it not for the resistance of the fluid in the cells of the battery, which prevents the direct return of the electricity from the conducting plate to the zinc, no voltaic action could be perceived, for the positive and negative electricity would be immediately neutralised. If, for instance, a good conducting medium were established by the introduction of mercury into the bottom of the cells, there would be very energetic chemical action; there would be the excitement of electricity, but it would be inappreciable, because it would be conducted back to the zinc plate as quickly as generated. It is evident, therefore, that without a resisting medium electricity could not be excited. It is equally true, though not at first so evident, that the exhibition of electric force, when excited, depends on the resistance made to its passage through the bodies on which it acts. Lightning passes imperceptibly through a thick metallic rod, but shivers into pieces an imperfectly conducting oak. The voltaic current also passes through a thick conducting wire without any observable effects; but when the same current is obstructed by a thinner wire it develops heat. Even in electro-chemical decomposition, it is found that the decomposing effect is diminished when the liquid undergoing decomposition conducts electricity too freely. If, however, the resistance be too great, the electric current is so far retarded as to diminish the action or to prevent it altogether; and it is difficult in some electro-chemical decompositions to determine how far the effect is increased or diminished by increasing or diminishing the conducting power of the solution.

The phenomena of induced voltaic currents present some of the most interesting and important facts in electric science. We shall have to notice this inductive action more particularly when considering the phenomena of electro-magnetism, but there are some points which come appropriately within the present division of our subject.

When contact is made and broken with the connecting wires of a single pair of plates, the wires used being thick and the circuit short, scarcely

any spark is visible on breaking contact; but when the current passes through a long wire, a bright spark, accompanied by a snapping noise, will be seen when the contact is suddenly broken. The effect increases to a certain extent with the length of the wire, and if it be twisted into a spiral the spark is more bright and the snapping sound is louder.

Such a result is directly at variance with the presupposed action of a voltaic current. As the resistance increases with the length of the wire, it might have been confidently predicated that the indications of electric force would decrease with the diminution of the quantity transmitted instead of being in any way increased. The phenomena of this anomalous action of the voltaic current in long resisting wires have been investigated by Faraday with the care and ability manifest in all his experimental researches, and he has succeeded in elucidating from them some highly-interesting facts.* It was ascertained that the spark on breaking contact becomes brighter, and the electric development stronger, in proportion to the addition to length of the conducting wire; until the resistance of the metal as a conductor so far diminishes the quantity of electricity as to interfere with the effect. Having attained the maximum result that mere addition to the length of the wire can give, the effect was much increased by twisting the wire into a spiral. The helix thus formed by coils of well-covered wire allowed the same quantity of electricity to pass as when the wire was straight; therefore so far as the direct action of the conducting wire was concerned the conditions were the same, though the amount of effect was different. The brightness of the spark and the strength of the shock were still more augmented by the insertion of a bar of soft iron within the coil of covered wire. It was evident, therefore, from these variations in the amount of force, whilst the length of the wire and its resistance to the electric current remained the same, that the increased effect could not be attributed, as was at first conceived, to momentum acquired by the electric fluid in its transmission through the wires.

Another remarkable fact developed in those researches was, that the extra current could be developed in a second and altogether separate wire placed parallel to the first; and that when the power was thus imparted to the second wire, the primary one, through which the direct action of the battery was communicated, appeared to be no longer specially affected on breaking contact. To produce the current in the second wire it was bent double, so as to form a continuous circuit, and extended alongside the primary wire; or, what was found still better, the first and second wires, insulated by being covered with cotton or silk, were twisted into a spiral together, and the two ends of the second were brought together to form a circuit. From these and from other facts elicited in the course of his experiments, Faraday arrived at the conclusion that the extraordinary development of electricity is derived from a current induced in the wires at the instant of breaking contact, and which is only momentary in its duration.

If any further proof were required that the currents thus induced are not dependent on increased energy in the conducting wire, it is afforded by the additional fact, no less curious than any other of these remarkable

* Experimental Researches, series ix.

phenomena, that the secondary currents are in the reverse direction of the primary. If, for instance, a voltaic current from the positive to the negative pole be suddenly broken, the induced electricity is of the opposite kind to that which is transmitted through the primary wire directly from the voltaic battery. Thus the electricity induced by breaking contact in the wire from the positive pole is negative, and that induced in the negative wire is positive.

A simple apparatus contrived by Faraday exhibits most satisfactorily the phenomena of induced currents, and the changes of their directions. A pair of zinc and copper plates, *z c*, were immersed in diluted acid; G and E represent cups of mercury, wherein contact was made and broken with the wires A B, which formed a circuit through a long conducting wire; two wires, N P, were attached to the long circuit, and could be brought into contact at *x*, or have an apparatus interposed there to indicate the direction and force of the induced currents. To produce a spark in the cross-wire junction, a piece of soft iron was placed in a helix at D, and the ends of the cross wires were rubbed lightly together whilst contact was broken at G or E by raising the wires A or B quickly from the mercury. In such circumstances a bright spark passed at *x* at the moment of breaking contact, none occurring at G or E; this spark exhibited the luminous passage of the extra current through the cross wires. When there was no contact at *x*, then the spark appeared in the mercury-cups when contact was broken; the extra current forcing its way through the cell of the pair of plates. On introducing a fine platinum wire at *x* no visible effects occurred so long as the contact was continued, but on breaking contact at G or E the fine wire was instantly ignited. Chemical decomposition was also exhibited by the cross-wire current by the introduction into the circuit of a piece of paper moistened with a solution of iodide of potassium; but the points at which the iodine and the potass appeared were the reverse of those at which they were disengaged by the direct current. This proved that the momentary current induced in the cross wires on breaking contact was in the contrary direction to the primary current. The same fact may be more clearly shewn by the introduction into the circuit of the cross wires of a galvanometer, an instrument which will be more particularly noticed with electro-magnetic phenomena.

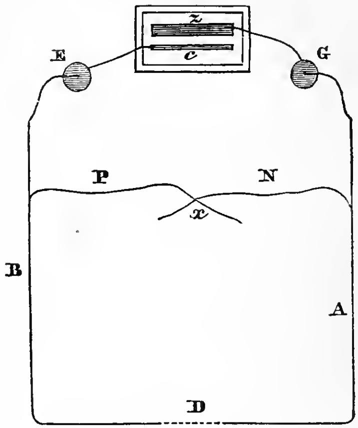


fig. 50.

In addition to the induction of an electric current on *breaking contact*, it has been satisfactorily proved that an extra current is also induced on *making contact;* the direction of the secondary current in that case being the same as the primary. In reference to the specific action of these induced currents of electricity Faraday observes: "From the facility of transference to neighbouring wires, and from the effects generally, the

inductive forces appear to be lateral, *i.e.* exerted in a direction perpendicular to the direction of the originating and produced currents. There can be no doubt that the current in one part of a wire can act by induction upon other parts of the *same* wire which are lateral to the first, *i. e.* in the same vertical section, or in the parts which are more or less oblique to it, just as it can act in producing a current in a neighbouring wire or in a neighbouring coil of the same wire. It is this which gives the appearance of the current acting upon itself; but all the experiments and all analogy tend to shew that the elements (if I may so say) of the currents do not act upon themselves, and so cause the effect in question, but produce it by exciting currents in conducting matter which is lateral to them." He also gives this important opinion : "Notwithstanding that the effects appear only at the making and breaking of contact, I cannot resist the impression that there is some connected and correspondent effect produced by this lateral action of the elements of the electric stream during the time of its continuance."

CHAPTER XIV.

ELECTRO-CHEMICAL DECOMPOSITION.

Decomposition of water—Transference of the elements through intermediate vessels—Faraday's hypothesis—Infinitessimally small particles acted on—Suspension of chemical affinity by Voltaic action—Supposed identity of chemical affinity and electricity—Decomposition of the alkalies—Remarkable combustion of paper by Voltaic action—Decomposition of metallic salts—Definite action ofelectro-chemical force—Electro-chemical equivalents—Absolute quantity of electricity in bodies—The quantity in a grain of water estimated—The Voltameter.

We have already noticed that a succession of sparks from an electrical machine, or a succession of discharges from a small Leyden jar, can produce the decomposition of many compound substances; and that in such decompositions certain elements attach themselves to the positive, and others to the negatively electrified wires. These effects, and this peculiarity of action, which are observable only on a very limited scale in frictional electricity, are largely and powerfully developed by the voltaic battery.

The decomposition of water affords one of the simplest and most satisfactory exhibitions of the decomposing power of voltaic electricity. A single pair of plates, when excited by diluted sulphuric acid, is not sufficient to produce the effect. The addition of another pair of plates imparts the required intensity, but only enough to exhibit the phenomena of decomposition in a feeble manner. With a combined series of twelve cells most compound substances may be resolved into their elementary constituents very satisfactorily. When the connecting wires from the opposite poles of such a battery are inserted into a glass containing acidulated water, there will be a copious discharge of gas from each, if the wires are tipped with platinum, the discharge from one of the points being more copious than from the other.

The form of apparatus represented in fig. 51 is well adapted for the collection of the products of the decomposition of water. Two glass tubes A, B, closed at the top, are filled with water slightly acidulated, and then inverted in a glass vessel of the same fluid, and held in position by the wooden lid D. To the bottom of the binding screws E, E, thick copper wires are soldered, which are bent under the tubes. The copper wires must be well varnished, excepting at their ends, which should be tipped with platinum. The wires from the battery are connected to the apparatus by the binding screws. When the battery is put in action, a discharge of bubbles of gas takes place from the ends of the two wires, which, rising through the water in the tubes, collect at the top of each. The quantity of gas evolved at the negative conducting surface exceeds that evolved at the positive surface, in the proportion of two to one, the former being hydrogen gas and the latter oxygen, in the exact proportions in volume that, when chemically combined, constitute water. When the positions of the wires connected with the poles of the battery are reversed, the hydrogen and oxygen are evolved from the opposite points; and under whatever circumstances the experiment is conducted, it is accompanied with the same result, even when decomposition is effected in separate vessels.

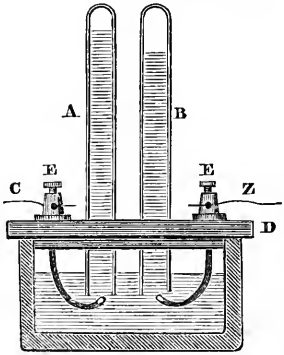


fig. 51.

Let the three glass vessels, 1, 2, 3, containing acidulated water, be arranged as in fig. 52, connected with filaments of wetted thread or asbestos *b b′*, and introduce into the two extreme glasses small strips of platinum-foil connected with the opposite poles of a voltaic arrangement.

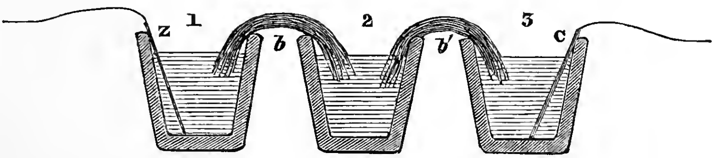


fig. 52.

When the voltaic current passes from *c* the positive surface, to *z* the negative, oxygen gas will be evolved in No. 3, and hydrogen in No. 1, in the exact proportions that they were liberated when the wires were inserted in the same vessel. Under these circumstances, it will be observed that the hydrogen element of the particle of water decomposed, which is separated from the association with oxygen at C, must pass through the filaments *b′*, through the fluid in the central vessel, through the second filaments *b*, and through the water in glass 1 to *z*, where it is evolved. No variation in the amount of battery power employed produces any alterations in the proportions of the gases evolved: the only difference attending the increase of the electric force is to increase the quantity of the gases evolved, the proportions being in all cases those that combine together to form water. When the experiment is arranged with conducting

surfaces of metals that easily combine with oxygen, hydrogen only is evolved, the oxygen portion of the decomposed water entering into combination with the metal. It is for this reason that, when the two gaseous products of the decomposition are required to be collected, platinum or gold points should be used.

If we assume that the process of decomposition is strictly limited to the same particle of water, and that the separation of its two elements takes place either at C or Z; that portion of the elemental gas which appears at the other wire must traverse invisibly through the three vessels, must rise through the two bundles of filaments, and descend again, without any portion of it escaping. But according to the view taken by Faraday of voltaic decomposition, as already explained,* the process is not confined to a single particle of the fluid, but each particle in the chain of communication is decomposed. Thus, commencing at *c* (fig. 41), the particle of water decomposed yields up its oxygen at that point, and the gas rises directly to the surface. The adjoining particle of fluid is also decomposed, but latently, the oxygen separated from that second particle instantly combining with the hydrogen liberated from the first, and parting with its own atom of hydrogen to the next particle; this transfer of the hydrogen element being continued through all the particles of fluid in succession until it arrives at the other battery termination, where, the series of decompositions being ended, the hydrogen is liberated and rises to the surface as a bubble of gas. According to this hypothesis, which has received very general acceptation, the hydrogen liberated in bubbles at one wire is not the same that was associated with the oxygen evolved at the other pole, but there is a complete cycle of voltaic changes, each particle of fluid in the chain of communication having undergone decomposition and recomposition with different though exactly equal atoms of the same element.

The particles of water acted on during decomposition are most probably infinitessimally small. A bubble of hydrogen gas the one hundredth part of an inch in diameter is distinctly visible, and one million of such bubbles would be contained in a cubic inch. Assuming the bubbles to constitute an entire cube of gas, fifty of such cubes would weigh only a single grain; and taking into calculation the oxygen element of the water, the evolution of a bubble of hydrogen gas $\frac{1}{100}$th of an inch in diameter indicates that a particle of water has been decomposed which could not have weighed more than the sixteen-millionth part of a grain.

The arrangement of the three glass vessels with asbestos connexions (fig. 52) will serve to illustrate, in a still more remarkable manner than the decomposition of water, the peculiarity attending the transfer of the elements of the decomposed body through an intermediate solution. A solution of muriate of soda (common salt) being put into glass 1, a solution of ammonia in 2, and an infusion of litmus in 3, it will be found that the muriatic acid combined with the soda in No. 1 will be transferred through the ammonia without combining, and will be collected in the glass containing the litmus, as will be indicated by colouring it red. In this case, therefore, it will be observed that the acid separated from the salt in No. 1 is conveyed through a solution for which it has, in ordinary circumstances, a strong chemical affinity; but under the influence of voltaic electricity the action of chemical affinity appears to be suspended.

* Page 100.

In the same manner the elements of numerous other compound substances may be transferred through solutions of alkalies or acids without exhibiting any disposition to combine. This peculiar influence of the electric current is confirmatory of Faraday's hypothesis respecting the mode of electric conduction through fluids. By that hypothesis the apparent suspension of chemical affinity in the intermediate vessel is attributed to the continued transfer of the acid from particle to particle of the fluid with which it ultimately combines, no free acid being actually liberated till the chain of connexion is terminated by arriving at the opposite pole of the battery.

The powerful influence of voltaic electricity in controlling chemical affinities led Sir Humphrey Davy to infer that chemical affinity is itself a modification of electric attraction, and that those bodies which combine most energetically possess inherently, and in the greatest degree, positive and negative electricities. Considering, therefore, chemical affinity and electricity to be identical, he conceived that the voltaic battery would afford the means of separating the most intimately combined elements by overpowering the attractive force with which they are held together. Acting on this opinion, he applied the power to the alkalies, which he and other chemists had predicted to be compound substances. The result of these investigations constitutes one of the greatest triumphs of analytical chemistry; for by this means those important substances, the earths and alkalies, were discovered to be oxides of peculiar metals, distinct in many of their qualities from any of the metallic bodies previously known.

The battery power employed by Sir Humphrey Davy was equal to that of 274 pairs of plates four inches square; but even with this powerful apparatus it was not till after numerous failures that he succeeded in decomposing potass. The difficulty experienced was to bring the voltaic influence to act upon the alkali; for in a dry state the non-conducting property of the potass stopped the electric current, and when dissolved, the power of the battery was spent in the decomposition of the aqueous solvent. To apply the electric force to the alkali itself, Sir Humphrey Davy adopted the expedient of making a crystal of potass transmit a current by the moisture of the breath on its surface. This had the desired effect, and the appearance of a globule of metal (potassium) at the negative pole of the battery was a glorious reward for his intelligent and persevering investigations.

The decomposition of the alkalies does not, however, require a powerful voltaic arrangement. This fact was experienced by the author in a somewhat annoying manner when experimenting with the copying electric telegraph, the action of which depends on making marks on paper by electro-chemical decomposition. The paper was well moistened with a solution of prussiate of potass in diluted nitric acid, and the voltaic current passed through the paper from a steel wire connected with the positive pole of the battery. The effect intended to be produced was to decompose the prussiate, and to cause it to combine with the iron of the wire to make a blue mark on the paper. The battery power employed consisted of two troughs of a Cruikshank's arrangement, each containing fifty pairs of plates two inches square. With this battery the paper was not only marked with a deep blue line as the steel wire was

drawn along, but when not moving rapidly it was actually set on fire, for a small bright flame accompanied the steel, and burnt holes through the paper. The cause of this combustion was at first perplexing, as paper cannot be ignited by the direct action of voltaic electricity however powerful. The smell of hydrogen gas shortly resolved all doubt, by indicating the combustion of potassium. The voltaic current, small in quantity as it was, had decomposed the prussiate-of-potass solution in the paper; and as quickly as potassium was formed, it was inflamed by combining with the oxygen of the aqueous solvent.

The decomposition of metallic salts by voltaic electricity deserves special consideration, from the circumstance that it forms the basis of the important art of electro-metallurgy, which has already become of great practical utility, and promises to be extended much more generally.

The processes of electrotyping and electro-gilding will be particularly noticed among the applications of electric science; we shall now, therefore, only consider the nature of the action of electricity in producing metallic deposits.

When a voltaic current is transmitted through a solution of sulphate of copper, the water which holds the metallic salt in solution is the substance decomposed, the deposition of the metal being a secondary result. The hydrogen, disengaged from its particle of water at the conducting surface connected with the positive pole of the battery, on being transferred to the negative surface combines with the oxygen that holds the copper in solution, and the metal is deposited. Thus, when small plates of copper connected with the poles of the battery are inserted in the solution, the oxygen liberated from the decomposed water is not evolved, but enters into combination with the copper, and forms with the sulphuric acid a particle of sulphate of copper, which is immediately dissolved. Neither is the hydrogen on reaching the metal plate connected with the negative pole evolved in the form of gas, but it combines with a quantity of oxygen in the metallic solution, equal to the quantity with which it was associated in the original particle of water decomposed, and thus forms a new particle of water; whilst the copper, held in solution by the oxygen, is deposited over the surface of the metal plate. By the continuation of the process the copper from the positive plate is gradually transferred to the negative plate; not, it will be observed, by the direct decomposition of the sulphate of copper held in solution, but by the action and reaction of the oxygen and hydrogen liberated from the decomposed water.

There is great difference in the facility with which different compound substances yield up their elements to the controlling force of voltaic action. Iodide of potass may be decomposed by a single pair of plates feebly charged. Muriatic acid and diluted sulphuric acid may be decomposed with a single pair when the energy is increased by nitric acid, but a combination of three or more plates is generally required to produce decomposition in other bodies. This difference in the facility with which different bodies may be decomposed by an electric current is attributed to the different intensities of their chemical affinities, those substances whose atoms are held together by the strongest affinities offering greatest resistance to the decomposing force.

The interesting and important fact has been clearly established by Faraday, that electro-chemical force is definite in its action, and that the

chemical power of a current is in direct proportion to the absolute quantity of electricity that passes. The expression of the theory by Faraday is, "that the chemical decomposing action of a current *is constant for a constant quantity of electricity*, notwithstanding the greatest variations in its sources, in its intensity, in the size of the electrodes used, in the nature of the conductors (or non-conductors) through which it is passed, or in other circumstances."*

The demonstration of this theory by numerous experiments tends strongly to confirm the opinion that electricity and chemical affinity are the same force differently modified; for it is found that the amount of decomposing effects in all substances agrees very closely with their chemical equivalents.

To those not acquainted with the nature of chemical combinations, it may be desirable to state that the elements of bodies always unite in definite proportions; for instance, eight atoms of oxygen unite with one of hydrogen to form water, and one atom of oxygen combines with five of potassium to constitute potass; and those elements will not combine in any other proportions. Many elementary substances unite differently to form different substances, but those proportions are always multiples of the first, and for the constitution of any given substance they will only combine in constant definite proportions. For example, if oxygen and hydrogen gases are mingled together in the proportions of ten to one, and then exploded in a close vessel, it will be found that chemical combination has taken effect only between those quantities of the gases required to form water, and that the two portions of oxygen in excess remain in the vessel not affected by the explosion.

The law by which the combination of elements is regulated in definite proportions to constitute any single substance, is found also to extend reciprocally to all substances whatever. The operation of this law is clearly exemplified in the mutual action of acids and alkalies. Thus, six parts of potass neutralise five of sulphuric acid, and four parts only of soda produce the same effect. These proportions of six to four prevail in the relations of potass and soda to all the acids; and this being known, the quantity of either required to saturate any other acid can be ascertained without experiment. For instance, as the saturating power of soda for sulphuric acid exceeds that of potass in the inverse proportion of four to six, and it being known that 4·4 parts of potass saturate five of nitric acid, it is easily computed that as 6 : 4·4 : : 4 : 2·93; the number 2·93 representing the parts of soda equivalent to potass in saturating nitric acid. The equivalent proportions in which all bodies combine with one another may thus be computed, after having determined experimentally the proportions of one or two combinations.

The amounts of electric force required to separate the elements of bodies from their combinations correspond in a remarkable manner with the chemical equivalents of the same bodies. For instance, 8 parts by weight of oxygen, which combine with 1 of hydrogen to form water, combine in the proportions of 32 with copper, 58 with tin, and of 103 with lead; and the same amount of electric force that is required to separate 8 parts of oxygen from water, will, by secondary action, separate

* Experimental Researches, series vii.

copper, tin, and lead from their solutions in the proportions of 32, 58, and 103; corresponding with their chemical equivalents. So closely have these numbers been found to agree in numerous experiments, that electricians do not hesitate to apply the more strict results of direct chemical analysis to the correction of the resnlts of electro-chemical decomposition.* In reference to this subject, Faraday observes, "I think I cannot deceive myself in considering the doctrine of definite electro-chemical action as of the utmost importance. It touches by its facts, more directly and closely than any former fact or set of facts have done, upon the beautiful idea that ordinary chemical affinity is a mere consequence of the electrical attractions of the particles of different kinds of matter; and it will probably lead us to the means by which we may enlighten that which is at present so obscure, and either fully demonstrate the truth of the idea, or develop that which ought to replace it."

The discovery of the law of the definite action of electro-chemical force, and that the chemical power of an electric current is in direct proportion to the quantity of electricity that passes, has shewn the way to the determination of the absolute quantities of electricities belonging to different bodies in their natural states. This interesting subject of inquiry is opened by Faraday in the seventh series of his invaluable *Experimental Researches in Electricity*. "Considering," he observes, "this close and twofold relation, namely, that without decomposition transmission of electricity does not occur, and that for a given definite quantity of electricity passed, an equally definite and constant quantity of water or other matter is decomposed; considering also that the agent, which is electricity, is simply employed in overcoming electrical powers employed in the body subjected to its action; it seems a probable and almost a natural consequence, that the quantity which passes is the *equivalent* of, and therefore equal to, that of the particles separated; *i. e.* that if the electrical power which holds the elements of a grain of water in combination, or which makes a grain of oxygen and hydrogen in the right proportions unite into water when they are made to combine, could be thrown into the form of a current, it would exactly equal the current required for the separation of that grain of water into its elements again."

The enormous quantity of electric power contained in a single grain of water is exemplified by the following experiment. Two wires, one of platinum and one of zinc, each one-eighteenth of an inch in diameter, placed five-sixteenths of an inch apart, and immersed to the depth of five-eighths of an inch in acidulated water consisting of one drop of oil of vitriol and four ounces of distilled water, and connected at the other extremity by a copper wire eighteen feet long and one-eighteenth of an inch in thickness, yields as much electricity in little more than three seconds of time as a Leyden battery charged by thirty turns of a very powerful electrical machine in full action. This quantity, though sufficient if passed at once through the head of a cat to kill it, is evolved by the action of so small a portion of the zinc and water, that the loss of weight sustained by either is inappreciable by the most delicate instruments.

By continuing the experiment until a grain of water was decomposed, it was ascertained that one grain of water requires for its decomposition a

* Experimental Researches, series vii.

continued current of electricity for three minutes and three quarters, which current must be powerful enough to retain a platinum wire $\frac{1}{104}$th of an inch in thickness red-hot in the air during the whole time. Making a comparison by the loss of weight of zinc oxidised during the action, it appears that 800,000 such charges of a Leyden battery as that referred to would be necessary to supply electricity sufficient to decompose a single grain of water. Thus, "zinc and platinum wires one-eighteenth of an inch in diameter and about half an inch long, dipped into dilute sulphuric acid so weak that it is not sensibly sour to the tongue or scarcely to our most delicate test-papers, will evolve more electricity in one-twentieth of a minute than any man would willingly allow to pass through his body at once. The chemical action of a grain of water upon four grains of zinc can evolve electricity equal in quantity to that of a powerful thunder-storm."*

In further proof of the high electric condition of the particles of matter, and of the equality of proportions of that belonging to them with that necessary for their separation, Faraday carefully collected the results of the action of an amalgamated zinc plate and a plate of platinum when immersed in diluted sulphuric acid in the proportion of 1 of acid to 30 of water. The quantity of oxygen and hydrogen gases evolved measured 18·232 cubic inches; equal in weight to 2·3535544 grains, which was therefore the weight of the water decomposed. The weight of the zinc plate was diminished 8·45 grains; and 2·3535544 grains, the weight of water decomposed, is to 8·45, the quantity of zinc oxidised, as 9 is to 32·31. These numbers correspond with the equivalent numbers of water and zinc; which shews that for an equivalent of zinc oxidised, an equivalent of water was decomposed.

The decomposing power of electricity has been employed as a measurer of the strength of a voltaic current. The fact that the amount of decomposition is proportioned to the quantity of electricity being taken for granted, it is only necessary to measure the quantity of gases evolved from water within a given time, to determine the force of the electric current. Instruments of this kind were contrived by Faraday, and were frequently used by him in his experimental researches. Fig. 53 represents the form of the instrument suitable for general experiments. A graduated tube D, of even bore, is ground or cemented into one of the openings of a two-necked bottle, B. Two platinum wires, $p\,p'$, are fused into the glass and penetrate within the tube, where they are connected with two small platinum plates. If the bottle be two-thirds full of diluted sulphuric acid, the fluid will fill the tube when the bottle is inverted, and will not flow out when placed upright. An electric current being then passed through the tube by connexion with the wires $p\,p'$, the gases evolved against the plates collect at the top, and the quantities are measured by the displacement of the water. When the instrument is in use the stopper is taken out of the second opening, to allow the enclosed air to escape as the water descends from the tube.

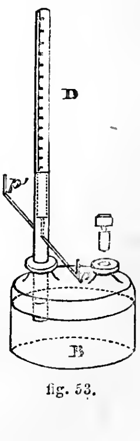


fig. 53.

* Experimental Researches.

CHAPTER XV.

ELECTRO-MAGNETISM.

Effect of Voltaic currents on magnetic needles—Magnetism induced in the conducting wire—Directions of deflected magnetic needle by opposite currents—Multiplication of effect by coils of wire—Galvanometers, their extreme sensitiveness—Magnetic action of copper wires—Polar direction of a wire coil—Electro-magnets—Their great power and limited spheres of attraction—Ratio of diminution of attractive force—Proportionate sizes of wire and iron—Economical effect of long coils—Great rapidity of electro-magnetic action—Residual power in electro-magnets—Medical coil machines—Rotary motion of conducting wires.

A current of electricity transmitted by wires from one end of a voltaic battery to the other meets with great resistance, even when passing through the metals that are the best conductors. The amount of this resistance, it has been already stated, is proportioned to the square of the diameter; and it increases rapidly, in some ratio not exactly ascertained, with the length of the conducting wire. The action and reaction that are thus continually in operation during the passing of a voltaic current produce remarkable magnetic effects, which extend to a considerable distance beyond the surfaces of the conductors.

The influence of frictional electricity in magnetising and demagnetising steel needles was known to Franklin and other of the early electricians; but it was reserved for Professor Œrsted of Copenhagen to discover, in 1819, the much greater magnetising influence of a current of voltaic electricity; and that that influence is exerted, not by transmitting the current directly through the bar to be magnetised, but by a secondary action in the conducting wire.

If a thick copper wire *c z*, connected with the opposite poles of a voltaic battery, be placed over a magnetic needle N S balanced on its centre like the needle of a compass, and in the line of the magnetic meridian, the needle will be deflected the instant that the current passes through the wire; and it will remain deflected from its natural position in a greater or less degree according to the strength of the current. If the current from the copper, or positive, pole of the battery pass from the north to the south pole of the magnetic needle, the deflection will be towards the east; but if the current pass in the opposite direction, the deflection of the needle will be towards the west. If the wire be then placed below the needle, the action will be reversed: the north pole of the needle, which was deflected to the west when the wire was above it, will be deflected to the east. A similar reversal of the deflections of the needle occurs when the direction of the electric current is changed by reversing the positions of the connecting wires.

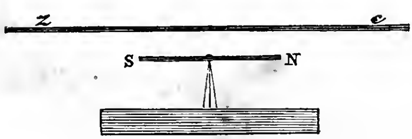


fig. 54.

The conducting wire seems to be endued with polarity at right angles

to its axis, as if an infinite number of small magnets were ranged side by side transversely to the direction of the current. The transmission of the electric current, indeed, appears to convert the conducting wire into a compound cylindrical magnet, every point of the surface of the cylinder being a magnetic pole with its opposite pole in the centre of the wire.

It is not essential that the conductor should be metal. Charcoal, and even acids, will, when conducting a current of electricity, become temporary magnets, and deflect the magnetic needle when it is placed parallel to the flow of electricity. The same power is exerted by the battery itself; for if a long magnetic needle be suspended from its centre over the cells of a voltaic arrangement, it will be deflected in the same manner as a needle balanced over a conducting wire.

As the needle is deflected in opposite directions when the wire is placed above and when it is below, it appears, on the first view, as if the magnetic influence were changed by the alteration of position; but the change is in reality only apparent. Let C Z, $c' z'$ represent the conducting wire, with the current passing in the direction of the arrows from C to Z. The magnetic needle *n s* is balanced on a pivot fixed to the wire, so that it may be turned round with it; and being held in a vertical position, and a trifle heavier at one end, it will not be affected by terrestrial magnetism. The wire on the left in the figure shews the north pole of the needle deflected towards the right hand. Turn the wire gradually round until it is brought into the other position, and then the north pole of the needle seems to be deflected in the contrary direction, though in relation to the wire it has remained unchanged; the apparent difference being caused entirely by its being seen from the opposite side.

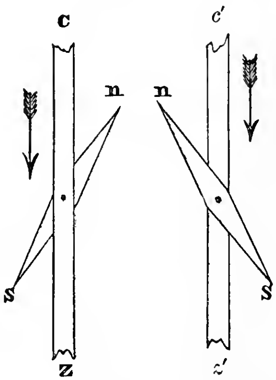


fig. 55.

Bend the conducting wire Z C into the form of a rectangle, and place a balanced magnetic needle in the centre of it, as in fig. 56; the end C of the wire being connected with the positive pole of the battery, and the end Z with the negative, or zinc end. The effect of this arrangement on the needle will be, in the first place, to deflect N towards the east by the influence of the current from C passing over the needle from north to south. The same current, if it were to return *over* the needle from S to N, would neutralise its first influence by the change of direction, and would bring the needle back to its original position. But by passing *under* it, the direction of the current in reference to the needle is reversed, and the influence is exerted to increase the first deflection towards the east, and the force of the current is thus doubled. By bending the wire again in the same manner an additional

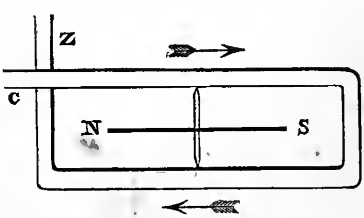


fig. 56.

effect is produced; and by numerous reduplications of this kind the influence of the current may be so multiplied, that the needle will be deflected by a quantity of electricity far too minute to have any sensible effect if passed over it through a single wire.

It will, perhaps, render this double action of the voltaic current on the

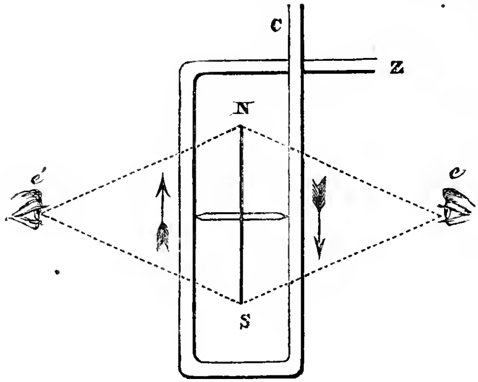


fig. 57.

needle more clear if the same arrangement be placed vertically, as in fig. 57. The electric current from the positive pole of the battery passing from the north to the south pole of the needle, deflects it towards the right hand of a spectator placed in the position of *e*, and towards the left hand of a spectator at *e'*. The same current on its return towards Z passes from the south to the north pole of the needle; but as it passes on the opposite side, the return current tends further to deflect the needle in the same direction, and it continues to point to the right hand of the spectator at *e*, and to the left hand of the spectator at *e'*, instead of changing positions as it appears to do in fig. 55, when seen on opposite sides during the passing of a single current.

The instruments called galvanometers, employed for indicating the presence of a feeble electric current, are constructed on the foregoing principle; and as each coil of wire that surrounds the needle seems to increase the effect, it might be supposed that the sensitiveness of such an instrument could be indefinitely extended. But there are limits to the length of the wire-coil, beyond which the sensitiveness of the needle is diminished instead of being increased. For instance, the influence of the conducting wire diminishes with its distance from the needle, and that distance becomes greater and greater with each additional superposed coil. With a view to increase the number of spirals as much as possible without lessening the effect by increased distance, very fine wire is used; which being carefully covered with silk or cotton, to prevent lateral conduction, may be wound on a rectangular bobbin close together, having a space in the middle for the introduction of the magnetic needle. In the galvanometers employed for the electric telegraph it is customary to wind round the needle about 150 yards of covered wire as fine as a hair. But when such a length of very fine wire is used, the great resistance it offers

to the passage of the electric current operates materially against the sensitiveness of the instrument, and currents of feeble intensity meet with so much obstruction that the quantity which passes is scarcely appreciable; the otherwise augmenting effect of the reduplication of the wire being more than counterbalanced by the increased resistance.

As a magnetic needle when suspended horizontally is attracted towards the north and south by the magnetism of the earth, it is necessary, when a single needle galvanometer is used, to place the coil in the magnetic meridian parallel to the needle; but the sensibility of the instrument is diminished by the directive influence of the earth, which tends to prevent the deflection. This defect may, however, be remedied, by attaching to the vertical support of the needle within the coil a second magnetised needle above the coil, with its poles in a reversed position; so that the directive tendency of the one being overcome by that of the other, the needle remains in a neutral state in whatever position it may be placed. This contrivance, which was first applied by Professor Cumming of Cambridge, and afterwards improved upon by Chevalier Nobili, has given such increased sensitiveness to the galvanometer that it indicates the presence of the most minute trace of a voltaic current.

Fig. 58 represents one of the approved forms of this kind of galvanometer, which has obtained the name of "astatic multiplier." A bent brass

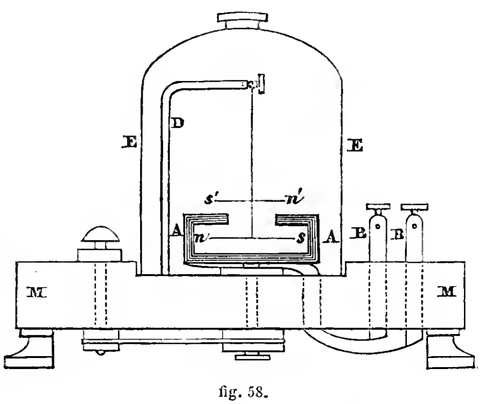


fig. 58.

standard D screwed into the mahogany base M M serves as a support whence the magnetised needles $n\ s$, $s'\ n'$ are suspended by a filament of unspun silk or by a human hair. The coil A A is formed of copper wire one-sixtieth of an inch in diameter and two hundred feet long, carefully covered with silk.* The coil is made by binding the wire round a thin wooden frame, the top and bottom of which are about two inches square and half an inch apart. The ends of the wire pass through the base, and are soldered to the binding screws B B. The needles are formed of pieces of thin watch-spring, flattened and strongly magnetised, or fine light sewing needles will answer the purpose. They are fixed on to a piece of straw with their

* Messrs. Watkins and Hill had a very delicate galvanometer at the Great Exhibition, the coil of which contained 230 yards of wire $\frac{1}{150}$th of an inch in diameter.

poles in opposite directions, the straw being attached vertically to the suspending hair. One of the needles is within the coil, the other about a quarter of an inch above it. A circular piece of card divided into 360° is fixed on the top of the coil, the upper needle serving as the index to mark the degrees of deflection. There are screws, not marked in the diagram, for adjusting the card and the needles to their proper positions, and the instrument is covered with a glass shade E E to protect the needle from the influence of currents of air.

When it is required to examine the development of electricity, connexions are made with the binding screws B B, so that the current may pass through the coil and deflect the needle. The intensity of the current is generally as the sine of the angle of deviation. This instrument is so extremely sensitive in its indications of an electric current, that if a drop of water be placed on the top of one of the brass binding screws, and it is touched with a zinc wire connected with the other binding screw, the needle will be deflected. The galvanometer is specially valuable in experiments with feeble currents of voltaic electricity, which are altogether inappreciable either by the gold-leaf electrometer or the voltameter.

In the preceding illustrations of the magnetic properties of a wire conducting an electric current, the peculiarity of the phenomenon is, in some degree, masked by the intervention of the magnetic needle. Other experiments shew more directly that the copper wire through which the current passes is for the time converted into a magnet.

Twist three feet of covered copper wire, about the thickness of bell-wire, round a pencil, so as to form, when the pencil is withdrawn, a hollow compact coil of wire, in form like a common bell-spring. Support the coil horizontally on a pivot, so that it may turn round freely, and let the wires at the ends dip into concentric cells of mercury, as represented in fig. 59, each cell being connected with one of the poles of a voltaic battery. The instant that the current is sent through the coil it will begin to oscillate, and after a short time will place itself in the magnetic meridian. If a magnet be brought near to either end of the coil, it will be attracted by one of the poles and be repelled by the other, exactly in the same manner as a steel magnet similarly poised. On reversing the connecting wires, so as to send the current through the coil in the contrary direction, the magnetic poles will be changed, as will be indicated by the turning round of the coil, the end that before pointed to the north being then directed towards the south.

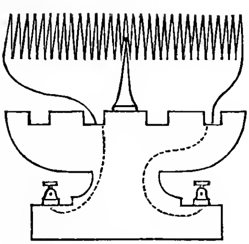


fig. 59.

The direction in which the wire of the coil is twisted also influences the position of the poles. When twisted from right to left, the current from the copper end of the battery will impart different polarity to that which a coil twisted from left to right possesses. That end of the coil at which the positive current is transmitted from left to right always points towards the north.

If the coil be doubled on itself by continuing to twist the wire in the same direction over the first single spiral, the magnetic properties will be considerably increased; and they will continue to be increased by adding

to the thickness of the coil, until the resistance offered to the current by the increased length of wire counteracts the multiplying tendency of the redoubled wires. The magnetic power of such a coil becomes wonderfully augmented by introducing a bar of soft iron within it. The iron becomes in that case powerfully magnetic the instant that contact is made with the voltaic battery, and the magnetism ceases almost as instantaneously when the electric circuit is broken.

The electro-magnet thus formed by surrounding a bar of soft iron with covered copper wire owes its magnetic property entirely to the electric current that circulates round it. The iron seems to act as a conductor and concentrator of the force, and appears to bear the same relation to the coil that the metallic coating does to the glass of a Leyden jar. It may be presumed that the same amount of magnetism is excited when the iron bar is withdrawn from the coil as when it is inserted; but without it the power is diffused through the wire, and is not concentrated so completely at the poles. Iron possesses almost exclusively the peculiar property of thus conducting and concentrating the magnetic force. Even a steel bar produces scarcely any effect when introduced within the coil, unless the voltaic current proceeds from a combination of several pairs of plates; and when magnetism is thus imparted to steel, it does not disappear when the voltaic circuit is broken, but the steel bar becomes a permanent magnet. Why iron of all the metals should be thus peculiarly affected,* and why the slight modification it undergoes in being converted into steel should produce such a change in its powers of receiving and retaining magnetism, are at present among the unsolved mysteries of science.

A bar of soft iron bent into the shape of a horse-shoe, and then covered with coils of copper wire twisted upon it in the same direction, constitutes an electro-magnet of the most powerful kind. A straight and flat piece of soft iron N S, sufficiently long to reach across the two ends of the bent bar, is attracted towards it with more than double the force that a single bar magnet exerts.

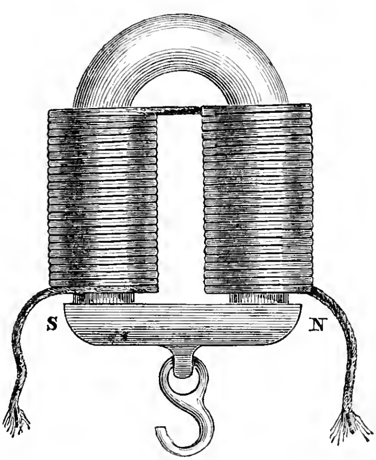


fig 60.

That the force should be doubled might have been expected, because there are two poles acting on the piece of iron instead of only one. The additional attraction is occasioned by the induction of magnetism in the connecting piece, which is called the keeper or armature of the magnet. That part of the keeper in connexion with the north pole of the electro-magnet has southern polarity induced in it, and the opposite end becomes a north pole. Thus the keeper, during the time of contact,

* Of the other metals, nickel possesses magnetic properties in the highest degree, but the power is so feeble as not to deserve notice in this general survey.

becomes a second magnet, and the attractive power exerted between the two is increased almost in the same proportion as if the keeper were a permanent steel magnet.

An electro-magnet of the horse-shoe shape, half an inch in diameter and five inches long, with three or four spirals of covered wire of the thickness of bell-wire twisted round each limb in the same direction, and excited by only a single pair of plates four inches square, will lift several pounds.

The magnetic power to be obtained by a current of electricity very far exceeds what can be permanently imparted to steel. An electro-magnet constructed by Mr. Joule was shewn in the Great Exhibition, capable of lifting a ton weight; and electro-magnets of larger size have been made that lifted several tons. The most powerful permanent magnet in the Great Exhibition weighed 101 pounds, and lifted 436 pounds.

Though the attractive power of an electro-magnet is so enormous when the surfaces of the keeper and of the magnet are in close contact, the sphere of its influence is extremely limited. The thickness of a sheet of paper introduced between them will diminish the power more than one half, and at the distance of half an inch apart scarcely any attraction will be perceptible. The influence of a permanent steel magnet extends considerably farther than that of an electro-magnet. The ratio in which the power decreases by distance has not, we believe, been determined; but there is good reason to suppose that magnetism of both kinds obeys the same law as all central radiating forces, and that the diminution is proportioned to the square of the distance.

It may, indeed, appear at first sight irreconcilable with the observed difference in the extent of the influence of permanent and electro magnets, that the ratios of decrease should be alike in each; but the seeming discrepancy vanishes if we suppose the centre of attractive power to be more deeply seated in the steel, which becomes permanently magnetic by some retentive power in its particles combined together as a whole, than in the soft iron, which acts only as a conductor of the magnetic force induced in the copper wire by the electric current.

Figure 61 represents one of the poles of a permanent bar magnet. Assuming the focus of attraction to be situated at C, a point equally distant from the sides of the bar and from the upper surface, then the lines B C, D C, drawn to that centre, will shew by their radiation the ratio of decrease of the magnetic power by distance in the same manner as, if C were the centre of an emanating force, they would indicate its proportionate diminution of energy. For example: let C be one quarter of an inch from the upper surface of the steel bar, and assume the attractive force at the surface to be equal to lift one pound. Then, if the force diminish according to the square of the distance, at a quarter of an inch from the surface, that is at twice the distance from the centre of force, the magnet would lift a quarter of a pound; at the distance of half an inch it would lift the ninth part of a pound; and at the distance of three quarters of an inch, that is at four times the distance from the centre of attraction, it would lift one-sixteenth part of a pound.

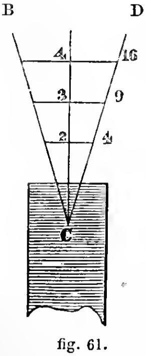


fig. 61.

Let us next consider the effect of the diminution of force in an electro-magnet with a similar ratio of decrease. The centres of attraction are assumed to be on the surface, or, for the sake of calculation, one-hundredth part of an inch beneath it; the weight that the magnet will lift being one pound, as in the former case. Then, assuming the ratio of decrease to be the same, at three times the distance from the surface that the surface itself is from any of the centres of attraction, the power will be reduced as before to one ounce; but the measured distance will now be less than the thirty-third part of an inch, instead of three quarters of an inch, for the point whence the ratio of decrease commences is nearly on the surface of the magnet. At the distance of three quarters of an inch the power would be reduced to less than the five-thousandth part of a pound.

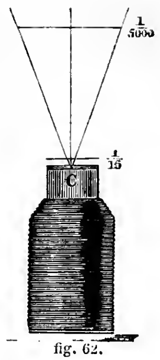


fig. 62.

The intensity of electro-magnets, or the spheres of their attractions, increases with the intensity of the voltaic current, and with the number of the coils of wire that surround them. Thus a bar of soft iron a quarter of an inch in diameter, covered with numerous coils of fine wire, and excited by a battery of twelve pairs of plates, will have a greater attractive distance than a bar half an inch diameter, with a fewer number of coils of thick wire, and excited by a single pair of large plates, though the latter magnet may sustain a heavier weight when the surfaces are in contact.

In making an electro-magnet, regard should be had to the relative thicknesses of the soft iron and the wire that is to form the coil. Small bell-wire, number 16 gauge, is suitable for bar-iron half an inch in diameter. A rod of about five inches should be bent into the form of a horse-shoe, having each limb of equal length, and the two ends filed perfectly flat and even. A length of 100 feet of wire, carefully covered with cotton, coiled round both limbs in the same direction, either from right to left or left to right, will make a magnet which, when excited by a current from two pairs of plates six inches square, will lift upwards of ten pounds. Mr. Shepherd, the inventor of the gigantic electro-magnetic clock of the Great Exhibition, who has had great experience in the construction of electro-magnets, adopts a very convenient plan for facilitating the winding of the coils. The wire is not twisted immediately upon the iron, but on separate short lengths of brass tube of sufficient diameter to admit the iron, which is inserted after the coils have been separately made. By this means the coils of wire may be readily

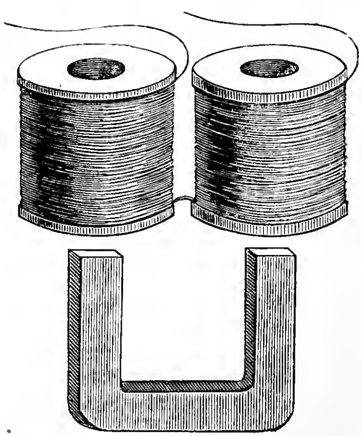


fig. 63.

wound to any length that is desired. The diagram represents the coils and iron detached from each other.

A shorter length of thick wire will produce as strong an attractive force as a long coil of thin wire, because though the multiplying effect by the reduplication of the coils is less, it allows a much larger quantity of electricity to pass. The use of the thick wire is, however, attended with a greater loss of battery power. It is an object, in an economical point of view, to extend the length of the coil as far as practicable without diminution of magnetic force, for by that means an equal amount of power is gained with a feebler current; the reduplication of the wire compensating by its repeated efforts for the diminished quantity of electricity which will pass in a given time through the greater length of wire.

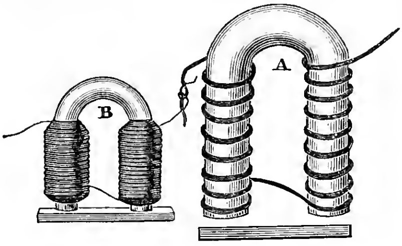


fig. 64.

To illustrate the advantage gained by numerous coils of wire, let a voltaic current pass through two electro-magnets A, B, joined together in the same circuit; A being large and covered with a few coils of thick wire, and B a smaller magnet with numerous coils of fine wire. The magnetism of A will be extremely feeble at the same time that B is energetically attractive; though when connected separately with a voltaic battery of a single pair of plates, A may be the stronger magnet of the two.

The greater consumption of zinc in the battery in imparting magnetism by short coils of thick wire is indicated by the rapid evolution of gas in the cells when the circuit is short, compared with the action when it is transmitted through a long circuit, though the latter is capable of producing an equal effect by a multiplication of the coils.

The electro-magnets used for telegraphic purposes, in which great sensitiveness is required, with a current very small in quantity but of considerable intensity, are made of iron about three-eighths of an inch in diameter, coiled round with nearly two hundred yards of extremely fine wire covered with silk. The keepers of these electro-magnets are attached to a slender spring to force them back when the circuit is broken, and they are adjusted to a distance of not more than the tenth of an inch from the magnet. These electro-magnets work briskly through a circuit of upwards of 400 miles, with a battery consisting of 100 pairs of plates.

The rapidity with which magnetism is imparted to soft iron on making contact with a voltaic battery appears to be simultaneous with the transmission of the electric current. An apparatus represented in the annexed diagram is admirably calculated to shew the extreme rapidity of electro-magnetic action. A short bar electro-magnet A is mounted on a wooden stand B. A piece of brass is fixed to the top, which serves for the attachment of a small keeper K to the magnet, and for the support of a bent brass arm C, used for the purpose of applying an adjusting screw S. The keeper is attached to a slender spring, which forces it from the magnet against the screw when the voltaic current is not passing. One of the poles of the battery V is connected directly with the lower end of the

coil-wire by the binding screw Z, and the other wire N is connected with the screw S, against which the keeper presses. The arm C is insulated from the brass to which the keeper is fixed by being screwed into a piece of box-wood, and the other end of the coil of wire is connected by the binding screw E with the keeper. By this arrangement the electric circuit is completed through the coil, by passing through the bent arm and through the keeper. The points of contact should have small pieces of platinum soldered to them to prevent corrosion of the metal, which would otherwise soon stop the action.

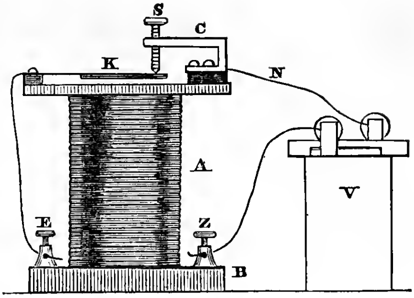


fig. 65.

The instant that the keeper is attracted towards the magnet, its contact with the screw is broken, and the voltaic current is interrupted. The magnet then ceases to act, the keeper is forced against the screw by the spring, and the contact being again renewed, the electro-magnet is brought into action as before, but to be again instantaneously demagnetised by attracting the keeper. It will be observed, therefore, that the circuit is broken every time that the keeper is attracted by the magnet, and renewed when forced back against the screw; and that each movement of the keeper indicates that the iron has been magnetised and demagnetised. When the voltaic battery is put in action, the keeper of the electro-magnet is attracted and forced back again with a rapidity altogether incalculable by the eye; the vibrations being so rapid as to produce a humming sound, which is more grave or acute according to the rapidity. By turning the screw S, so as to bring the keeper more close to the electro-magnet, the rapidity of the vibrations increases with the increased attraction of the magnet; and by the musical note thus occasioned, the vibrations of the keeper have been estimated to exceed two hundred in a second.

Though magnetism can be imparted with this amazing rapidity, the amount of magnetic power is in such cases by no means equal to that which the electro-magnet exerts when the contact is of longer duration. Only a given quantity of electricity can be excited by the battery in a given time; and assuming that it requires chemical action to be continued one-tenth of a second to obtain the full power of the battery, when the contact is made and broken more frequently than the tenth part of a second the quantity of electricity that passes is very considerably less, though the diminution is not proportionate to the shortness of the contact. It appears, indeed, from the result of numerous experiments on this subject made by the author, that the full effect of an electro-magnet, with a coil of thirty yards of thick wire, cannot be obtained more frequently than four times in a second.

When the keeper of a horse-shoe electro-magnet is in contact with the two poles, some magnetic power is retained after the contact is broken; and to prevent the continuance of the induced magnetism it is requisite to interpose a piece of card or thin leather, so that the keeper and the

magnet may not touch each other. Besides this retention of magnetism by the keeper, the electro-magnet itself retains its power for a short time, if the bar of soft iron be above three or four inches long; therefore, to ensure rapid action when the contact is made and broken rapidly, it is desirable that the iron round which the wire is coiled should be as short as possible.

The self-acting mode of breaking contact, represented in fig. 65, has been applied with great advantage in constructing apparatus for giving shocks by secondary currents of electricity for medical purposes. A great length of very fine covered wire is twisted round the primary coil of thick

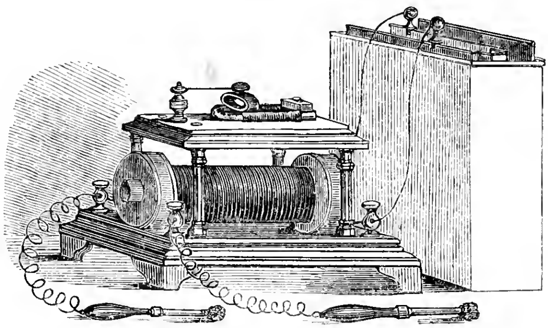


fig. 66.

wire through which the voltaic current passes; and each time that contact is broken, a secondary current is induced through the fine wire. Brass handles are soldered to the ends of the second wire to increase the surface contact when grasped by the hands, or conducting plates are used when the electricity is transmitted through other parts of the body. The making and breaking contact by the self-acting vibrations of the keeper produce a rapid succession of shocks, the strength and rapidity of which may be regulated by the adjusting screw.

Reverting to the deflective action of a conducting wire on a magnetic needle, it will be observed that the action is a tangential one; that is, the direction of the force is at right angles to the radius of the wire. One pole of the needle is deflected to the right hand, the other pole to the left hand; and whatever side of the wire the needle is placed, the same effects take place. Thus, if the conducting wire were surrounded by a number of magnetic needles ranged parallel to it, they would be all deflected in the same manner, evidently shewing that the deflecting force acts tangentially at every point of the circumference of the wire. The effect of a tangential force acting on all parts of the circumference is to communicate rotary motion to bodies free to move, in the manner that a wheel is turned round by impelling it at the circumference in directions at right angles to its radius. As there cannot be action without reaction, and as hey are always equal and in opposite directions, the tendency of the force exerted by the conducting wire is to cause its rotation about its own axis, and to communicate motion in the opposite direction to the magnets within its influence.

Faraday, who was the first to take this view of the character and

tendency of the electro-magnetic force, succeeded in illustrating it most satisfactorily by experiment. To do this, it was necessary to remove the counteraction of one of the poles of the magnet on the other; for as the south pole of a magnet is deflected in the opposite direction to that of the north pole, the contrary forces, when allowed to operate, completely neutralise each other. The simplest arrangement for producing the rotation of a magnet is that shewn in fig. 67. Into the bottom of a wooden cup A, made to contain mercury, is inserted a wire *d*, to which a bar magnet is attached by a thread. When the cup is filled with mercury, the steel magnet being the lighter rises to the top, and is retained in an upright position by the thread. A thick wire *c*, connected with the positive pole of a voltaic arrangement, dips into the mercury, but is insulated from it by being covered with cotton and varnished, excepting at the end. When a voltaic current is transmitted through the conducting wire, it influences the north pole of the magnet; but after communicating with the mercury it is so diffused that the south pole is not affected. By this means the tangential force with which the induced magnetism in the conducting wire acts on the north pole is not counteracted, and the magnet being free to move in a circular direction, begins to rotate round the conducting wire.

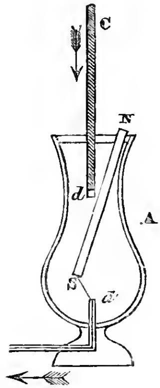


fig. 67.

Fig. 68 shews another form of apparatus for illustrating this remarkable phenomenon. Two long but light magnets N S, N′ S′, are fixed into a circular piece of wood D, which rests on a pivot B, so as to turn round easily. The conducting wire *c*, from the copper end of the battery, dips into a cup of mercury in the wood, and by means of mercurial connexions the electric current is conducted through the wire Z to the negative end without passing near the southern poles of the magnets. The connexion with the battery being completed, the magnets rotate freely round the conducting wire in the direction from left to right, like the hands of a watch. On reversing the battery connexions, so that the positive current may enter

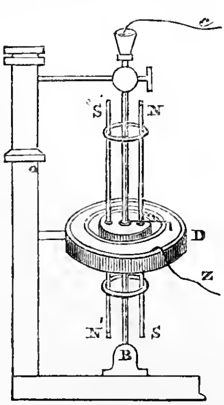


fig. 68.

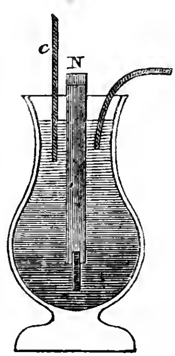


fig. 69.

at Z and return up the wire to *c*, the direction of the rotation is changed. A similar change in the direction of the motion also occurs when the position of the poles of the magnets is reversed.

The rotation of a bar magnet on its own axis may be effected by an arrangement similar in principle to the foregoing. The contrivance originally proposed by M. Ampère is the simplest. The magnet N (fig. 69) is allowed to float in mercury, being kept in a vertical position by a weight of platinum; and the action of the electric current is confined to one pole of the magnet by insulating the conducting wire *c*, with the exception of its end, and introducing it vertically into the mercury to the depth of half the magnet. The counteraction that would otherwise occur from the other pole is thus prevented, and the magnet rotates slowly on its axis.

CHAPTER XVI.

MAGNETO, THERMO, AND ANIMAL ELECTRICITY.

Induction of electricity by magnetism—Multiplication of effects by motion—Magneto-electric machines: their powerful effects—Magneto-electric spark—Decomposition by magneto-electricity—Correlation of magnetic and electric forces—Development of electricity by heat—List of thermo-electrics—Thermo-electric batteries—Indications of temperature by thermo-electricity—Animal electricity—Electrical organs of the torpedo—Identity of animal and voltaic electricity—Electrical power of the gymnotus—Connexion between nervous influence and electricity.

It might have been inferred *à priori*, from the induction of magnetism by electricity, that electricity could be induced by magnetism. The verification of this inference is one among the many facts for which electric science is indebted to Dr. Faraday.

The simplest mode of inducing electricity by magnetic action is by an arrangement of permanent magnets and an electro-magnet shewn in the diagram.

Two long permanent bar-magnets N S, N S are placed in the manner represented, with their opposite poles joined at one end and spread out at

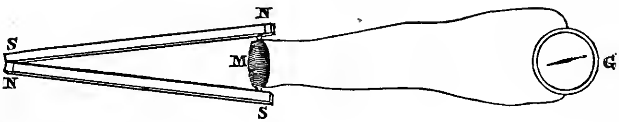


fig. 70.

the other; each of the separated poles being in contact with a bar electro-magnet M, round which there is coiled about 200 feet of covered wire, the 60th part of an inch in diameter. The ends of the coil of wire are connected with a galvanometer G, placed at such a distance from the magnets as to be beyond their direct influence on the magnetic needle. Whilst the magnets continue thus connected, the galvanometer will not indicate any trace of electricity; but at the instant that contact is broken, a current of electricity is induced in the coil of wire, and the galvanometer is strongly deflected. The effect is, however, only instantaneous, and the needle, after

a few vibrations, returns to its normal position. On making contact again, the galvanometer is again deflected; but the deflection is in the contrary direction to that on breaking contact, the electricity being equally temporary, and being in other respects like that of the secondary currents induced on making and breaking contact with a voltaic battery. The more suddenly contact is made and broken by jerking away either of the magnets, the more powerfully is the galvanometer deflected.

The current of electricity induced by the arrangement shewn in fig. 70 is very small in quantity, even when the most powerful magnets are employed; but the further researches of Faraday led to the discovery of new modes of action, by which the current may be prodigiously increased, and all the effects of a powerful voltaic battery, either of high intensity or of great quantity, may be produced by permanent magnets without any battery whatever.

Faraday was stimulated to his investigations on this subject by the remarkable phenomenon observed by M. Arago, of the induction of magnetism by motion in substances not otherwise magnetic. The French philosopher discovered that if a copper disc be revolved close to a magnetic needle, it is deflected, and that when a magnet is so suspended that it may rotate in a plane parallel to that of the disc, the magnet tends to follow the motion of the disc; or if the magnet be revolved, the plate tends to follow its motion, and the effect is so powerful that magnets or discs of many pounds weight may be thus carried round. This effect, M. Arago stated, not only takes place with the metals, but with all substances, solid or liquid, and even with gases. It must be observed, however, that in repeating these experiments, neither Mr. Babbage, Sir John Herschel, nor Dr. Faraday was able to produce the effect with any substances that were not very good conductors of electricity.

The experiments conducted by Faraday with the view of elucidating these phenomena, led him to the conclusion that whenever a metallic body is put in motion close to a magnet, a current of electricity is induced, which ceases the instant that the motion ceases. As the movement of any metallic body, such as a disc of copper, in close proximity to the poles of a permanent magnet was found to induce a temporary electric current in the metal, Faraday inferred that the effect would be increased if, instead of a copper disc, a coil of covered copper wire round a bar of soft iron were used. This was tried with most satisfactory results; and other electricians have applied the principle to the construction of magneto-electric machines, that excite torrents of electricity by the rapid rotation, close to the poles of a powerful permanent magnet, of a piece of soft iron surrounded by coils of covered copper wire.

Fig. 71 represents a magneto-electric machine. A powerful compound permanent horse-shoe magnet *a* (composed of several thin plates of steel separately magnetised and bound together,) is fixed in a horizontal position. The soft iron covered with copper wire *c d*, by the rotation of which the electricity is induced, resembles a horse-shoe electro-magnet; but instead of being a bent bar of soft iron, it is made of two short straight bars connected together by a cross-piece of soft iron. This form is adopted because it facilitates the winding of the numerous coils of wire, and is more convenient for the mechanical arrangements. When intensity effects are required to be produced, the iron of the rotating electro-magnet, called

the armature, is of small diameter, and about fifteen hundred yards of very fine insulated wire are coiled round both limbs. When quantity effects are wanted, the armature is made of iron of greater diameter, and the coil consists of one-tenth the length of wire about the thickness of bell-wire. The armature is fixed on to a spindle attached to a small grooved wheel that is worked by a band over a larger wheel, by which means very rapid motion may be given to the armature. Wires, through which the induced

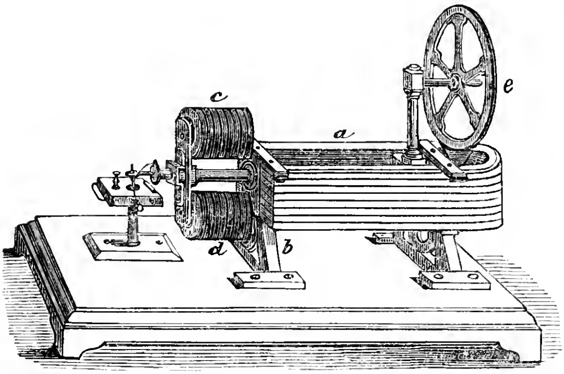


fig. 71.

electricity is conducted, are connected with each end of the coil of wire round the armature; and as the latter revolves as closely as possible to, without actually touching, the poles of the magnet, alternate currents of negative and positive electricity are transmitted. Arrangements are made, either by projecting points dipping into mercury, or by springs pressing on interrupted collars of metal, for breaking the circuit of the wire coil the instant that the two ends of the armature come opposite the poles of the magnet; by which means the rotating electro-magnet becomes magnetised and demagnetised twice in every revolution, and at each break in the circuit a current of induced electricity is transmitted through the coil.

When the armature with the long coil of fine wire is used, a succession of very severe shocks passes through the body on communication being made between the wires by grasping two conducting metal cylinders. The decomposition of water, and of all compound bodies that are decomposable by voltaic electricity, may also be effected, and a rapid current of most brilliant sparks is emitted at the points when contact is broken. With the armature of thicker and shorter wire, the metals may be ignited, and all such effects can be produced as may be obtained from a voltaic combination of a few large-sized plates. The sparks, on breaking contact, are also brighter, but no shock is given by the quantity armature.

In these experiments, the parts of the copper with which contact is made and broken should be amalgamated with nitrate of mercury, or by applying a drop of nitric acid, and then rubbing over it a particle of mercury. Good contact is essential to the success of all experiments in electro-magnetism, and to ensure it, it is customary to employ mercury, and to amalgamate the connecting points that dip into it. The liquid metal

is, however, apt to be thrown about, and it is attended with other inconveniences. When solid points of contact are employed they should consist of platinum. With the other metals, the ignition of small particles by the secondary current on making and breaking contact forms an oxide of the metal on the points, which, after a short time, interrupts the electric circuit; but platinum, being the most incorrodible of the metals, is not liable to have its surfaces oxidised.

The quantity of electricity induced by magnetism is proportionate to the power of the magnets employed. In a very large and powerful magneto-electrical machine constructed by Mr. Clarke, the *magnet battery* consists of 106 cast-steel bars, each four feet long, and when combined weighs 156 pounds. With this machine, a cubic inch of gas from the decomposition of water is evolved in one minute and a half, the shocks are too powerful to bé received without danger, and the sparks, when the quantity armature is used, are accompanied with a loud snapping noise like the discharge of a Leyden jar.

The induction of electricity by magnetism alone seems to open an exhaustless source for the supply of electric force without the trouble, the annoyance, and the cost of voltaic batteries; but hitherto it has not been of much avail. The labour of turning the wheel for the rapid rotation of the armatures, and the irregularity in the force consequent on irregularity of mechanical action, are serious drawbacks to the use of magneto-electric machines as the generators of electricity for experimental purposes. As an economical means of exciting electricity for electro-plating, it was at one time thought to promise great advantage. A patent was obtained for the application of magneto-electricity to that purpose, and Messrs. Elkington constructed at their works in Birmingham a very large machine to be worked by steam-power; but it was not found to answer so well as voltaic electricity, in consequence of the want of continuity and steadiness in the electric current produced. Magneto-electricity has also been applied by Mr. Henley to work a needle telegraph with very good effect, as will be subsequently noticed.

As electro-magnets are far more powerful than any combination of magnetic steel bars, they have been sometimes used instead of permanent magnets for the induction of magneto-electricity, and with good results; but the employment of a voltaic battery to induce magnetism, which is afterwards to be applied to induce electricity, complicates the consideration of the action, and seems to render it doubtful whether the magnetism excites the electricity or the electricity excites the magnetism. This mutual transmutation of the two forces into one another proves, however, in the strongest possible manner, the intimate connexion, if not the identity, of electricity and magnetism. By some hitherto inscrutable modifications of the same common force, it is developed at one moment exerting limited though energetic attractions on steel and iron alone; at another it is operating on compound substances of every kind, separating their elements from the most intimate combinations; again, we see it emitting light that rivals the sun in brightness; now it is carrying lightning-messages through hundreds of miles of wire, rather than force its way through a gossamer web; and yet again, we see the same force dealing destruction in its course, as it rends a passage through the air from the clouds to the earth.

The development of heat being a characteristic phenomenon of an elec-

tric current, it was inferred that heat was also capable of developing electricity. The satisfactory proof of this inference is due to Professor Seebeck, of Berlin; and though this interesting branch of electric science has yet made no important progress, sufficient has been done to prove that heat, electricity and magnetism, are correlative forces.

All that is necessary for the development of thermo-electricity is to heat any metallic body irregularly at its extremities. The thermo-electric relations of metals have not, as at present ascertained, any connexion with their relative voltaic or conducting properties. In the following series the combination of the metals at the two extremes produces the strongest electrical effects, the effect of the intermediate metals in the series diminishing as they approach. Those at the top of the list, commencing with galæna, are positive to all below.

1. Galæna.	6. Tin.	12. Zinc.
2. Bismuth.	7. Lead.	13. Iron.
3. Mercury.	8. Brass.	14. Arsenic.
4. Platinum.	9. Gold.	15. Antimony.
5. Manganese.	10. Copper.	
	11. Silver.	

The arrangement shewn in the annexed diagram represents a simple thermo-electric circuit that exhibits the phenomena in a very satisfactory manner. The rectangle B D represents a frame of metal; the rectangular bar B C D being of bismuth, soldered at the corners B and D to a similar rectangular bar of antimony. A magnetic needle M is poised in the centre, and the whole is supported on an elevating stand. On applying heat to either of the corners B or D, the magnetic needle is immediately deflected, thus indicating that an electric current is passing through the bars. The quantity of electricity excited is, to a certain point, proportionate to the different degrees of temperature communicated to different parts of the same metallic bar, and does not depend on the absolute heat. Thus the application of ice will produce an electric current as well as the application of heat; and by applying ice to one corner and the flame of a spirit-lamp to the other at the same time, the effect is greatly increased.

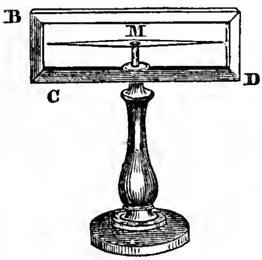


fig. 72.

The intensity of the thermo-electric current from a single circuit is extremely feeble, and is altogether impeded even by a short length of fine wire; but it may be greatly increased by multiplying the series, as in the voltaic pile. With a series of very short and thin bars of bismuth and antimony, having their alternate ends soldered together, and insulated from each other by pieces of thick paper, a very delicate thermometer may be constructed, which indicates, by the deflection of the galvanometer needle, variations of temperature much too minute to be appreciated by any other indicator of heat.

By multiplication of the series sparks have been produced, and electro-magnetic effects have been obtained. A vivid spark was elicited by Chevalier Antinori of Florence, on breaking contact; and Professor Wheatstone successfully repeated the experiment. He used a thermo-battery of

thirty pairs of bismuth and antimony, packed into a cylindrical bundle 1·2 inch long and three-quarters of an inch in diameter, with a coil of insulated copper ribbon 50 feet long and 1½ inch broad. Mr. Watkins, by using a thermo-electric battery of thirty pairs, each plate being 1·5 inch square and 0·33 inch thick, and heating one end of the arrangement with a hot iron, whilst the other was kept cool with ice, succeeded in exciting an electro-magnet to such an extent as to support a weight of ninety-eight pounds.*

M. Mellori and Professor Forbes have made valuable use of thermo-electricity in their researches into the nature of heat, as it affords the most delicate means of detecting variations of temperature. The apparatus of Professor Forbes is represented in fig. 73. The thermo-electric battery A, mounted on its stand, consists of thirty-six alternations of bismuth and antimony in very short and thin bars, connected at their ends, but insulated laterally by paper. The terminal elements of the battery are produced at C, to which thick copper wires connected with the galvanometer G are attached. In his experiments the deflections of the needle were examined through a magnifying instrument, so that the least movement might be observed. The instrument is so sensitive in its indications that the approach of the hand towards the end of the battery produces a deflection of several degrees.

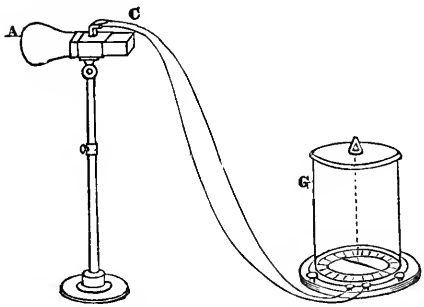


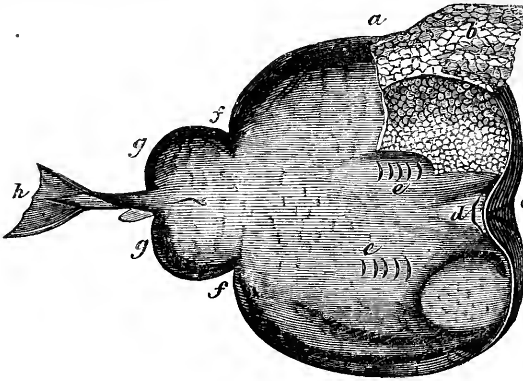
fig. 73.

Another source of electricity—the last we have to notice—is derived from the organisation of living animals. There are several fishes which possess the power of giving electrical shocks; but those best known in this country are the torpedo and the gymnotus. The former is found in the Mediterranean, and along the shores of France and the south of England. It is a species of ray. The electrical organs lie on each side of the head, and consist of a great number of hexagonal prisms, with their bases to one side of the fish and their apices to the other. Upwards of one thousand of these prisms have been counted in a single organ. The power of communicating shocks depends entirely on the nerves of the fish, for its heart may be taken out without diminishing the effect; but the instant that the nerves are divided the electrical power is lost. The back and the belly are in opposite states of electricity, that of the back being positive, and that of the belly negative; and to receive a shock it is necessary to make a communication between them.

The accompanying figure shews the fish with part of the skin turned over, so as to expose the right electric organ, which presents the appearance of a honeycomb. The mouth is shewn at *d;* the ten bronchial

* Dr. Golding Bird's Natural Philosophy.

apertures at *e e*; *f f* the outer margin of the great lateral fin; *g g* two smaller fins, and *h* the tail fin.



like Battery

fig. 74.

The electrical properties of the gymnotus, or electrical eel, are better known than those of the torpedo, because some living specimens exhibited in London, first in the Adelaide Gallery and now at the Polytechnic Institution, have enabled Faraday and other electricians to make experiments with the electricity evolved. The electrical organs are arranged from the head of the fish to the tail on each side of the spine, like a voltaic battery; the end near the head being positive, and the tail negative. The whole power of this living battery is exerted when connexion is made between the head and the tail; and if the communication be made between any intermediate parts, the effect is diminished in the same degree as in a voltaic battery under similar circumstances. On putting small live fish into the water with the gymnotus, the latter forms itself into a circle enclosing the fish, and sends a charge through the water, which instantly stuns its prey. When the hand is held in the water whilst the charge is transmitted, a shock is felt, though not so strong as when the gymnotus is touched at its two extremities.

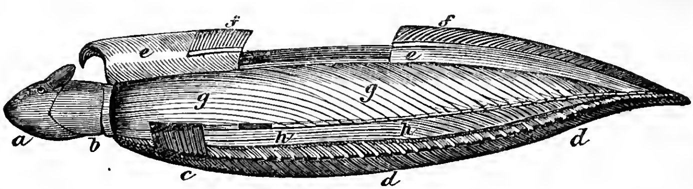


fig. 75.

Fig. 75 represents a gymnotus with the electrical organs laid bare, the skin being turned over on each side. Flat portions and cross divisions appear in parallel lines nearly in the direction of the axis of the body. They consist of thin membranes nearly parallel to each other; their breadth about the semi-diameter of the body, but of different lengths. In the figure, *a* represents the head; *b* the cavity of the body; *d d* the ventral fin; *e e* the skin turned back; *f f* the external muscles of the fin; *g g* the

large electrical organ ; *h h* the smaller organ. Fig. 76 presents two views of the entire fish.

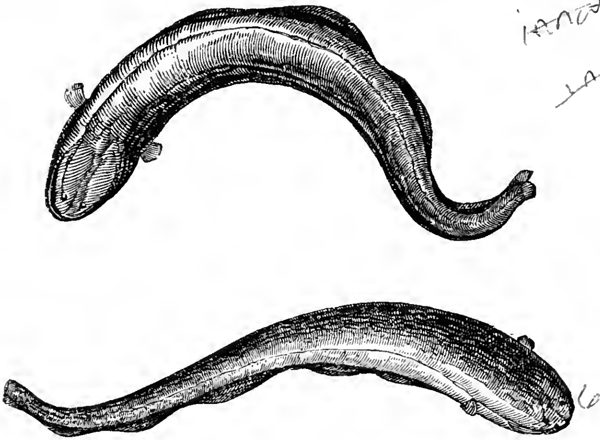


fig. 76.

In a series of experiments with the gymnotus, Faraday clearly established the identity of its peculiar power with that of voltaic electricity of great intensity. It produces a succession of shocks at short intervals ; it effects electro-chemical decomposition, evolves heat, emits sparks, affects the galvanometer, and renders iron magnetic. An attempt was made to estimate the power of the apparatus, and though the experiments were not very satisfactory, Faraday was led to conclude that a single medium discharge of the gymnotus is at least equal to a Leyden battery of fifteen jars containing 3500 square inches of glass, coated on both sides and highly charged.

The electrical eel experimented with was forty inches long, but it is found in the rivers and lakes of Venezuela six feet in length. Horses that venture into the pools where the gymnotus abounds are stunned by their shocks and often drowned. Humboldt mentions that on one occasion he witnessed about thirty horses and mules driven into a pool occupied by numbers of gymnoti, which glided under the bellies of the animals and discharged through them most violent and repeated shocks. The horses, convulsed and terrified, their manes erect, and their eyes staring with pain and anguish, made unavailing struggles to escape. The electrical energy of the eels, however, became exhausted in less than a quarter of an hour, and those horses that had contrived to keep above water during the attack recovered.

The power of developing electricity appears to be limited to about eight genera of the known fishes. Frogs and some other animals of low organisation are peculiarly sensitive to the influence of electricity, but it is very questionable whether they possess any voluntary power of its development. The experiment of the convulsion of the limb of a dead frog by making a communication between a muscle of the leg and a nerve, which has been adduced as a proof of the electricity of frogs, is altogether

distinct from that control of the electrical power which is exercised by the torpedo and gymnotus.

That there exists some intimate connexion between nervous influence and electricity there is little doubt. Many attempts have been made, and with some success, to prove that the human body generates electricity; and we have heard it publicly asserted, and maintained by ingenious arguments, that the lungs are galvanic batteries which are constantly generating vast supplies of the electric fluid, which are conveyed by the nerves to the brain, and thence distributed to the whole nervous system to stimulate the vital functions. Dr. Golding Bird affirms, that "it is quite indisputable that the human body is always in an electric state, but of the feeblest tension, never exceeding that evolved by the contact of a plate of zinc with a plate of copper. It increases with the irritability of the person, and appears to be greater in the evening than in the morning, and disappearing altogether in very cold weather."* It appears to be also certain that electricity exerts an influence on the germination of seeds, though the experiments hitherto made on this subject have led to no satisfactory results.

From the mysterious connexion which is known to subsist between electricity and the nervous system, it is but a step to attribute the influence of the imagination, and of other affections of the mind, to electrical causes. On this supposition is founded the belief in mesmerism; which assumes that an invisible electric fluid may be emitted by the power of will from the finger-ends of the operator, and be transfused into the system of the patient. It is not our intention to enter that debatable ground; we allude to the subject only as it is one of the most notable forms in which the prevailing opinion of the influence of an electric fluid on the vital functions has clothed itself. It is a deeply-interesting question, however, which still remains to be proved, whether the same force which, differently modified, produces electricity, magnetism, and heat, is also to be identified with the immediate stimulus of vitality.

CHAPTER XVII.

ECONOMICAL APPARATUS.

Simple form of apparatus for frictional electricity—Directions for constructing Electrical Machines—Leyden Jars and Batteries—Electrometers—Electrophorus—Universal Discharger—Voltaic Batteries—Electro-Magnets—Galvanometers—Observations on exciting liquids for Voltaic Batteries.

THERE are many students strongly inclined to explore the attractive regions of electric science, whose researches might add greatly to the stock of knowledge, and tend to the elucidation of the mysteries in which the relations of electricity to other forces and to the vital principle are shrouded; but they are deterred from advancing by the cost of the necessary apparatus. We propose, therefore, to assist in removing this obstacle by giving hints

* Elements of Natural Philosophy, p. 307.

for the construction of apparatus which any one possessed of a certain degree of mechanical skill can put together himself.

Every thing that is absolutely necessary for exhibiting the phenomena of frictional electricity may be provided at the cost of a few shillings, when no great amount of electrical force is required. The author, when a boy, made and experimented with an apparatus of the very simplest kind. His first exciter of electricity was a long bottle of the same shape as those in which eau-de-Cologne is contained, but wider and larger. An old piece of black silk, on which a little *aurum musivum* was spread, served for the rubber; and with this bottle, after it had been well dried before the fire, an energetic excitement of positive electricity was obtained by holding it in one hand and rubbing it briskly with the other. For exciting negative electricity a large stick of sealing-wax was used. With the glass electric a Leyden jar, consisting of a large glass tumbler coated inside and out with tin-foil to within an inch of the rim, was fully charged in a quarter of a minute. The discharging-rod was a piece of bent wire; and an insulated stand was formed of a piece of board mounted on a small phial cemented to the wood with sealing-wax. An electrical machine was afterwards made of equally simple materials. The cylinder was a large phial, into the hollowed bottom of which was cemented an axis, shaped with a knife to fit into the hollow at one end, and rounded at the other like a spindle. A rudely-constructed handle was cemented into the neck of the phial, and it was mounted upon two wooden supports fixed into a flat board to serve as the base. The prime conductor was part of the handle of a hair-broom, rounded off at each end and covered with tin-foil. It was mounted on a long narrow phial for its insulating support, and pins were stuck into the wood to collect the electricity. The cushion was supported on a wooden prop, and pressed against the bottom of the small cylinder. With this machine, sparks two inches long could be obtained, and it could fully charge the tumbler Leyden jar with about twenty turns of the handle.

With an apparatus so rude and costless in its construction, many of the most remarkable phenomena of electricity could be exhibited; but its diminutive size and rough appearance were scarcely suited for the laboratory of an adult experimental philosopher: we notice it merely to shew at what little expense electrical phenomena may be exemplified. We shall now describe a means of providing an apparatus of a better kind, suitable for all experiments with frictional electricity.

A length of stout glass tube, two feet long and an inch and a half in diameter, which may be purchased at a barometer-maker's for one shilling, serves as an excellent means of exciting electricity by manual friction. It should be varnished inside to prevent the moisture of the atmosphere from condensing and adhering to the glass, and it should be closed at each end with corks. *Aurum musivum* (sulphuret of tin), a small quantity of which may be purchased at an operative chemist's, serves even better than amalgam to stimulate the excitement of electricity by alternating friction.

The glass cylinders for electrical machines may now be purchased of various sizes from the philosophical glass-vendors. One of these, six inches in diameter, fitted into a frame consisting of a wooden base and two uprights made of baked wood, will answer for most purposes very well. The prime conductor may also be of wood, covered with tin-foil; its insulating support being a glass tube about nine inches long, varnished. Pins,

or pieces of brass wire sharpened at both ends, may be stuck into the wood to collect the electricity from the excited cylinder. The cushion, with its flap of silk attached, may be supported on an upright of well-baked wood firmly fixed into the wooden base, which will press against the side of the cylinder by the springy nature of the wood. A handle may be purchased to cement into the neck of the cylinder, it being of not much consequence whether it be insulated or not.

Leyden jars may be easily made by coating glass jars with tin-foil inside and out, the foil being made to adhere by a thin layer of paste. A thick brass wire, to serve for the connexion with the inside coating, should be supported in a firm position in the centre of the jar by a large cork, and a piece of thin wire must be attached to the bottom to make connexion with the inside coating. The object of having thick wire is to prevent the dissipation of electricity, which takes place from points and small surfaces. The end of the wire outside should, for the same reason, be covered with a hollow brass ball. Such balls, with screw-holes for the wires, may be obtained at the philosophical-instrument makers' for three pence each.

In forming a battery of Leyden jars, they should be fitted into a box about half their height, with partitions inside to prevent the jars from being broken by collisions; and the bottom of the box should be lined with tin-foil, to form a metallic connexion between the outside coatings. All the wires or knobs connected with the insides of the jars should also be joined together by wire. A battery of six quart jars, sufficient to deflagrate small strips of metal leaf, may thus be constructed at a cost of fourteen shillings.

An electrometer presents little difficulty. Four inches of glass tube two inches in diameter may be cemented on to a wooden stand, having first pasted two narrow strips of tin-foil one inch and a half long opposite to each other inside on the lower part of the tube. The strips of tin-foil should be connected together, and have also a metallic connexion outside the stand. A cork covered with tin-foil may be fitted into the top of the tube, instead of a metal cover, allowing a small piece of foil to project in the centre inside for the convenient attachment of two strips of gold-leaf. The gold-leaves should reach so far down as to be rather below the strips of foil on the side of the tube, taking care, in pasting them to the cover, that the metallic connexion is not obstructed by the paste or gum.

In making an electrophorus, recourse may again be had to wood covered with tin-foil, as a substitute for solid metal. Paste a disc of tin-foil nine inches in diameter on a flat board, and over the foil fix a disc of the same size of thick sheet gutta-percha, or pour over it some melted resinous cement, made as flat as possible. The conducting insulated plate may consist of a flat circular piece of wood, smaller than the cake of cement; the surface being covered with tin-foil, and having attached to the centre of its upper surface a piece of glass tube to serve for the insulating handle.

An universal discharger, insulating stands, and stools may be made by using short lengths of strong glass tube for the insulating supports. Gutta percha will be found a very convenient substance for many smaller parts of apparatus, as it may be easily moulded into form by immersing it in hot water, and no known substance is so good an insulator. By adopting

the plan thus sketched out, any person, with a little ingenuity and mechanical skill, may put together a very complete and sufficiently powerful apparatus for general experiments with frictional electricity, at a cost of less than two pounds.

Experiments with voltaic electricity, if continued, are more costly, because, in addition to the original expense of the apparatus, there is the constant consumption of the exciting materials. For those experiments, however, which do not require a numerous and powerful combination of plates, voltaic apparatus may be made at even less cost than that for frictional electricity. Zinc plates may be obtained at the metal-warehouses of various degrees of thickness, and cut into any size required, at the rate of fivepence the pound. It is not desirable to have the plates less than the eighth of an inch thick. They may be readily amalgamated by dipping them for a few seconds into diluted sulphuric acid, to clean the surfaces, and then sprinkling over them some globules of mercury, which may be rubbed on the zinc with the end of a cork.

The only part of the manipulation in making voltaic batteries that is attended with any difficulty, is the soldering of the metallic connexions. The method of doing it is, however, soon acquired, and with a brazier's small soldering-iron, a little soft solder, and some muriatic acid, the copper connexions and the binding screws may be soldered on to zinc plates without much trouble. A voltaic arrangement, consisting of two pairs of zinc and copper plates six inches square, may be fitted up in earthenware cells for four shillings. Such voltaic battery will ignite fine metal wires, decompose water and most other compound substances, powerfully excite electro-magnets, deposit metals from their solutions in the processes of electrotyping and electroplating, and, by inducing secondary currents, give strong electric shocks.

The large flat earthenware cells cost one shilling each; therefore it is most economical, when many combinations are required, to divide a long water-tight wooden trough into compartments by cementing into it square pieces of slate or thick glass, about an inch and a half apart.

Electro-magnets are very readily made. Having obtained from a smith some pieces of best soft bar-iron, bent into the shape of the letter U, wind round each limb a quantity of covered copper wire, observing to twist it round each in the same direction and as evenly as possible, and the magnet is complete. The quantity and thickness of the wire depend on the kind of magnet that is required, as previously explained.* Covered copper wire of the size of thick bell-wire (No. 14), which is the kind generally used for primary magnetic coils, is sold for three shillings the pound. Thirty yards of such wire are sufficient to make a powerful horseshoe magnet, with iron about half an inch in diameter and five inches long. The wire for inducing secondary currents should be wound upon the primary coil, but separated from it by a piece of silk; and medical coil-machines for giving shocks by secondary currents require at least 1000 yards of very fine covered wire. The finest silk-covered copper wire to be procured is as thin as a human hair. Its price is sixteen shillings the pound, and one pound of it contains 18,000 yards. Though wire of this extreme degree of tenuity is much used for secondary circuits and for

* Page 133.

highly sensitive galvanometers, it is questionable whether a rather thicker wire, that will allow a greater quantity of electricity to pass, is not to be preferred.

To construct a galvanometer in the easiest way, it will be advisable to purchase a common pocket-compass, which may be procured for two shillings. Fix on to the magnetic needle a very thin strip of paper at right angles to it, to serve for the index. Twist across the compass-box a number of turns of fine wire, so that the coil wound round it may be about half an inch wide and about a quarter of an inch in thickness. The galvanometer thus formed should be fitted into a small box open at the top, to enable it to be placed steadily, and through the sides of the box let the wires from each end of the coil project. When used horizontally, the compass should be so adjusted that the coil and the needle may be parallel to each other; therefore both will then be in the magnetic meridian, the needle being concealed by the coil. When the two ends are connected with any source of voltaic electricity, so that the current may pass through the coil, the needle will be immediately deflected, and the paper index will shew the direction and the amount of the deflexion. Simple galvanometers of this construction were employed by Dr. O'Shaughnessy on the first telegraphic lines in India, and they were found very efficient instruments at a distance of several hundreds of miles.

The exciting liquid for voltaic batteries most generally used is sulphuric acid, diluted with water in various proportions. When the zinc plates are well amalgamated, one measure of acid may be diluted with ten of water; but when the plates become worn a weaker solution is desirable. By this dilution local action is avoided, and the effect is equally powerful; because the zinc when worn exposes a larger surface, and is more easily attacked by the acid. When powerful action is not necessary, it is better to employ a much more diluted acid, in the proportion even of one to forty. Sulphuric acid, when purchased by the pound, is very cheap. A large stoppered glass bottle, containing ten pounds, may be bought for half-a-crown. Solutions of alum and of salt are good exciters when energetic action is not required. Sulphate of copper is also a good exciter of voltaic electricity; but when used, the zinc should be placed in a separate porous cell, containing diluted acid or a saline solution; otherwise metallic copper deposits on the zinc, when immersed in the sulphate, and produces counteraction.

The preceding remarks on the construction of economical apparatus, though not perhaps sufficient as explicit directions, will serve at least as hints to those who desire to exercise their ingenuity or to save expense. When neither motive operates, the student may supply himself with better apparatus than he can hope to make from any of the manufacturers of philosophical instruments.

PART III.

THE APPLICATIONS OF ELECTRICITY.

CHAPTER XVIII.

ELECTRIC TELEGRAPHS—MEANS OF COMMUNICATING.

First attempts to transmit messages by electricity—Conducting power of the earth—Opinions respecting the cause—Resistance of long wires to transmission—Voltaic currents—Modes of making electric communications—Difficulties of insulation—Defects of the present system—Submarine telegraphs—New plan proposed—Prospect of telegraphic communication with America.

The practical application of electric force to the requirements of civilised life can scarcely be dated beyond fifteen years from the present time; yet within that short period the power of electricity has been applied, with more or less success, to a vast variety of purposes. The transmission of lightning messages, the working of machinery, the chronicling of time, the lighting of streets, the manufacturing of metal utensils, gilding and plating, even sounding the depths of the sea, and the detection of the midnight burglar, are among the many varied uses to which electricity has been directed.

The rapid transmission of electric discharges through extended lengths of wire suggested, at a very early period of the history of electricity, the idea of its applicability to telegraphic purposes. The first plan for transmitting messages by that means of which there is any record, was that of M. Lesarge, of Geneva, in 1774. The signals were made by pith-ball electrometers, placed on insulated wires extended between the places with which communication was to be established. The discharge of a Leyden jar, on being sent through the wire at one end, caused the pith balls to expand on the other. There were as many insulated wires as letters of the alphabet, each one serving to indicate a separate letter; and, as the electric discharge was sent successively through the wires, by noticing those on which the pith balls expanded, the words to be transmitted were spelt.

Thus we perceive that at least seventy years before any electric telegraph was in practical operation, a plan for establishing such means of communication had been pointed out. Several other modes of making communications by frictional electricity were invented, which will be noticed in the next chapter; but most of them, like that of Lesarge, required a separate wire for indicating each letter. The discovery of voltaic electricity, and still more that of electro-magnetism, greatly added to the facility of transmitting signals; nevertheless twenty-six wires, one for each letter, were generally considered requisite; and the difficulty of forming an insulated

wire connexion through which the voltaic current may be transmitted without loss of power, is still the great difficulty in telegraphic communication, even when two wires only are employed for each instrument.

Before we describe the various modes that have been invented for transmitting electric messages, it is desirable that we should explain the means of making communication, and shew how the difficulties to be encountered may be overcome.

The experiments undertaken in 1747 by Dr. Watson and other Fellows of the Royal Society, at Shooter's Hill, on the conduction of electricity through wires supported on short posts, not only proved that at a distance of two miles the charge passed instantaneously, but also that the return circuit, of equal length, could be transmitted through the dry ground. In those experiments frictional electricity was employed, the discharge of a Leyden jar having been sent through the circuit. The force of voltaic electricity is comparatively so feeble, that scarcely any sensible current would pass through ground as dry as that purposely selected for its dryness in Dr. Watson's experiments; but when plates connected with the two poles of a voltaic battery are buried in *moist* earth, the conduction is so perfect, that at a distance of several hundreds of miles no appreciable quantity of voltaic electricity is obstructed by resistance. The honour of the discovery of the conducting power of the earth has been claimed in recent times, though the fact was established by experiment before the close of the last century.

The "earth-circuit," as it is called, is now made use of in all telegraphic communications, and is of great practical utility, not only because it diminishes the resistance to the electric current, but it effects also a considerable saving of expense. If wire communication alone were depended upon, it would be necessary to have one wire to conduct the current, and another to convey it back to the battery; but by introducing large copper plates into the earth at the corresponding stations, the return circuit is completed through the moist ground, and one wire is saved. This saving of wire, which in the case of a single circuit amounts to one-half, is not proportionally great when several circuits are employed; for a single wire will serve for the return circuits of any number that may be used, in the same manner as the earth.

The annexed diagram will explain more clearly the action of the earth-circuit. The letters A B represent the wires making communications be-

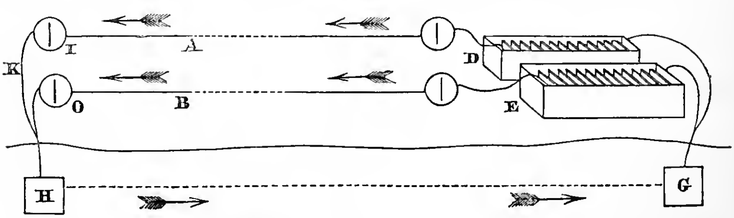


fig. 77.

tween the batteries D and E, and the telegraphic instruments I O, at the receiving station. The electricity from the copper end of the battery D would be conducted along A through the instrument I, by the wire K to

the earth-plate H. It would be then transmitted through the earth, on its return to the battery, in the direction of the arrows, to the other earth-plate G, and thence it would find its way to the zinc pole of the battery D, and complete the circuit. In the same manner the electric current from the copper end of the battery E would be transmitted through the wire B, and would complete its circuit also by means of the earth-plate H, and would traverse the course indicated by the arrows, and return to the zinc end of E. Though both electric currents traverse the same wire, from the instruments I O to the earth-plate H, and are thence transmitted through the earth to a single plate G at the transmitting station, there is no mingling of currents, the electric current of each battery being kept as distinct as if separate wires were used both for the transmitted and the return current. It would, indeed, be as impossible for the separate currents transmitted from the two batteries to be mingled together, as it would be for the written contents of two letters enclosed in the same mail-bag to intermix. The entire separation of the two currents, when transmitted through the earth, also takes place when a single wire only is used for the returning portion of the circuit. Suppose, for instance, the plates H and G, instead of being buried in the earth, were directly connected by an insulated wire, the current from each battery would be equally separate; but the resistance offered by the wire being very much greater than that of the earth, not nearly so much of the power of the battery would be transmitted.

Pure water is estimated to offer three million times the resistance of copper to the passage of an electric current. It seems, therefore, an anomalous fact, that the moisture of the earth should conduct electricity between two distant points so very much better than metal wires. The fact is, indeed, so contradictory to the known relative proportions of the conducting powers of water and metals, that attempts have been made to explain the phenomenon by assigning other causes than mere conduction. It has been assumed that the earth is a vast reservoir of electricity,* and that the positive current from the battery E, when it enters that reservoir, is at once transferred by some process different from that of conduction to the corresponding plate.

This opinion has received countenance in quarters that have given it more importance than it would otherwise seem to deserve, especially when it is well known that an imperfect conductor can compensate for its defective state of conduction by increase of volume. Take, for instance, the two metals copper and iron. Iron offers seven times the resistance of copper to the passage of an electric current; but by proportionally increasing the size of the iron wire, a current of electricity will be transmitted through it as readily as through the better conducting metal. In the same manner, by bringing into conducting action a large body of interposed moist earth, the electricity, which would not pass through a small quantity, is transmitted without any apparent resistance when a large sectional area is included between the plates buried in the ground.

Professor Matteuchi has made numerous experiments with a view to ascertain the amount of resistance offered by the earth to an electric current, and the mode by which the transfer is effected, the result of which

* Electric Telegraph Manipulation, by C. V. Walker.

is decidedly in favour of the opinion that the transmission is produced directly by means of conduction only. "If," as he observes, "the effect was caused by immediate absorption and reproduction, a mere contact with the earth would be sufficient; but it is essential that the plates buried in the ground should present a large surface, without which there is a comparatively small quantity of electricity transmitted." The Electric Telegraph Company generally bury a quantity of sulphate of copper with the earth-plates, so as to surround them with a good liquid conductor, which serves, practically, to increase the conducting surfaces that connect the poles of the battery with the earth.

The resistance of a wire to the passage of an electric current increases with its length, but not in direct proportion. In experiments by Professor Morse, of the United States, when using a battery of 100 pairs of plates, it was found that when the current was transmitted through one mile, one-third of the battery power was lost; at a distance of two miles, one-half the power was transmitted; and at a distance of five miles, only one-fifth the quantity of water could be decomposed in the voltameter, compared with the decomposing power of the battery when no length of wire at all was interposed. The resistance proceeded in a diminishing ratio until a distance was attained beyond which there appeared to be little further diminution of the power transmitted. The same result has been observed in the telegraph lines in England. The diminution of the electric current by resistance of the wire is not much greater at a distance of 200 miles than it is at a distance of 100, provided the insulation be very good; but if the insulation be imperfect, of course the loss of power will increase with the length of the circuit.

The difficulty of effecting perfect insulation of the wires is the greatest impediment to the establishment of telegraphic communication. The wires are either supported on posts, or they are covered with gutta-percha, and laid in trenches underground. The former plan is generally adopted. The posts are about fourteen feet high, and cross arms of wood D D (fig. 78), eighteen inches long, are fixed to them cross-wise, about ten inches apart. At each end of the short wooden arm balls of earthenware *b b* are attached, in the sides of which nicks are made to hold the wire; and these globes are covered with a cap of galvanised iron, to protect them from the rain, and to prevent the deposition of dew. The earthenware being an imperfect conductor of electricity, insulates the wires from the posts, and prevents the electric current from passing down them to the earth in wet weather. Balls of glass are beginning to be used instead of earthenware, as that substance is a better insulator. Iron wire, one-sixth of an inch in diameter, and galvanised to prevent corrosion, is the kind used in the telegraph lines of this country. As many as thirteen of these wires are attached to the posts on the North-Western Rail-

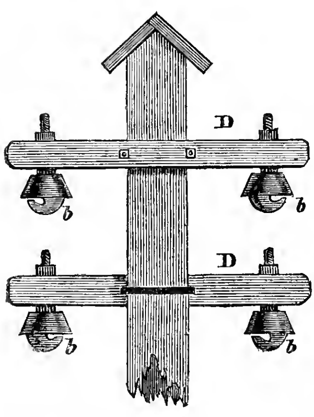


fig. 78.

way, near London. Some of them extend to Liverpool and Manchester, some to Glasgow, and some are connected with the intermediate towns.

By placing wires forming short circuits in close proximity to those of long circuits, the difficulty of insulation on the longer circuits is considerably increased. Let D I represent a wire extending from London to Liverpool, and E O one extending from London to Birmingham, both supported on the same posts within a few inches of each other. In a damp

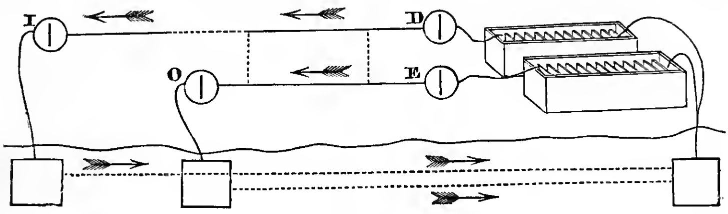


fig. 79.

state of the atmosphere, when there is any defect in the insulation of the wires, the electricity in its course along D I will be continually passing to the wire E O, as shewn by the dotted lines; for it can by that means take a shorter return-circuit by passing to the earth-plate of O, and thus return by the plate, which is common to both wires, to the battery of D, instead of traversing the whole of the long circuit to I. In this manner it not unfrequently happens that so much of the electric current is diverted that the telegraph instruments cannot be worked.

In the opinion of the author, the escape of electricity from the wire is greatly facilitated by the exposure of the wires in such close proximity to each other without any insulating coating. He brought this subject before the notice of the British Association for the Advancement of Science at the two last meetings at Ipswich and Belfast; and in the papers read by him on those occasions he endeavoured to shew that the greater part of the loss of electricity in damp weather is owing to the communication from wire to wire through the moist atmosphere, and is not occasioned by defective insulation at the posts. In this opinion several telegraphic engineers now agree; and to secure perfect insulation, not affected by rain or fog, it would be necessary to varnish or otherwise insulate the surfaces of the wires.

It is the opinion of many electricians that the low intensity of voltaic electricity effectually prevents it from passing from wire to wire, even through an atmosphere of fog. This opinion is, however, opposed to sound reasoning on well-established facts; and though on the small scale in which experiments can be conducted in a laboratory, no appreciable quantity of voltaic electricity will pass through the air, such limited means of observation are not to be depended on when the surfaces exposed are very great. Each iron wire from London to Liverpool exposes a surface of not less than 45,000 square feet; and between several surfaces of that extent, only six inches apart, there can be little question that a large quantity of the electric power must be transferred and lost when the air is charged with moisture.

The wires on the telegraph lines in India are thicker, and they are

placed at a greater elevation than in this country. The stronger wires were found to be necessary to enable them to support the large birds and the monkeys that perched and congregated upon them; and greater height was required to allow loaded elephants to pass underneath. Dr. O'Shaughnessy, the superintendent of the East India Company's lines, has also introduced the plan of making the posts stronger as well as higher, by which means they may be placed at greater distances apart; not more than eight posts being required in a mile. In this country it has been customary to consider the protection of a railway essential to the establishment of telegraph lines. The protection, however, that a railway affords is more imaginary than real; and in India the completion of a system of telegraphic communication over 2000 miles of country will precede the construction of railways.

When the atmosphere is in an electrical condition, the telegraphic instruments are often disturbed, though no current is transmitted along the wires from the batteries; and during thunder-storms the wire coils have been destroyed by lightning. To prevent this disturbance by atmospheric electricity, lightning-conductors are attached to the posts at certain distances.

In the underground plan of laying down telegraphic lines, the copper wires are covered with gutta-percha, and are then laid in trenches two feet deep. This plan is found more expensive than the suspension of wires on posts, and it has not, until recently, been adopted in this country, excepting under special circumstances, such as connecting the wires with the telegraph stations in towns by passing under the streets. In those cases it is usual to protect the wires by enclosing them in iron tubes. In Prussia the underground system was at first generally adopted; but it is giving way to the suspension on posts, as the gutta-percha coating was attacked by vermin when not enclosed in tubes. A successful underground line has been recently laid down along the common road from London to Dover, in connexion with the submarine telegraph to Calais, which may perhaps be the means of introducing that method more extensively into the telegraph system of England.

The plan that has been found most successful for submarine telegraphs is to enclose several copper wires, coated separately with gutta-percha, within a hollow wire cable, of which the insulated wires form the core. Cables of this kind, resting on the bed of the English Channel and of the German Ocean, now serve to transmit messages between England and the Continent, and answer the purpose remarkably well.

Fig. 80 shews the mode of enclosing the wires in their outer casing of

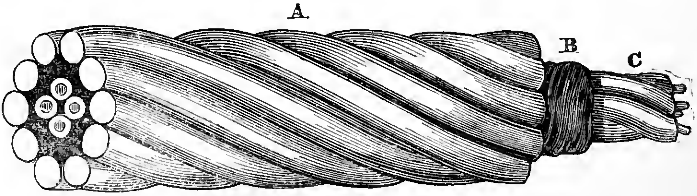


fig. 80.

iron. The protruding end C exhibits the copper wires covered with gutta-

percha, and twisted spirally; B is a covering of hempen twine, to form the core; A the cable of iron wire, and the other end shews a section of the whole.

The principal objection to that system is its cost. The cable from Dover to Calais, with four thin copper wires enclosed, cost, we understand, 20,000*l*.

Copper wire is used for submarine telegraphs, because copper is a much better conductor of electricity than iron; and as a thinner wire answers the purpose of conduction, it may be more easily insulated, and forms a smaller core for the external cable. This mode of forming submarine telegraphs is, however, in the author's opinion, open to many objections. All the failures that have occurred in endeavouring to establish submarine telegraphic communication have arisen from the breaking of the wires. The experimental wire across the English Channel broke shortly after the first signal was transmitted; it was the same with that from Holyhead to Dublin, though protected by a thick wire covering; and the first wire from Donaghadee to Port Patrick was cut in two by mistake. It seems highly objectionable, therefore, to continue the use of thin copper wire under circumstances which experience has shewn require additional strength. The rejection of thick iron wire, on the ground that it is more difficult to insulate than thin copper of equal conducting power, seems to be not well founded. As iron conducts electricity with less facility than copper, any defect in the insulating coating will have a less injurious effect than if an equal or a much smaller surface of copper was exposed; therefore, the difficulty of insulation would not be increased by the use of the stronger and less perfectly-conducting metal. The cable, it is true, would be thicker; but its strength would be increased in a very much greater proportion, and there would be much less danger of failure.

In forming a submarine telegraph it would be desirable not to employ many wires, which increase the difficulty of insulation, but to rely rather on increasing the rapidity of transmission by the use of superior instruments. The actual number of public messages transmitted by the Electric Telegraph Company between all parts of England and Scotland in the half-year ending in July 1852, amounted to 85,915; and that number might be transmitted through a single wire if the most rapid instruments were employed.

Having succeeded in connecting England with the continent of Europe by submarine telegraph, so as to transmit intelligence instantaneously from London to Brussels and Paris, the problem that remains to be solved is, to effect similar communications with America, the East Indies, and Australia. It has, even at present, almost resolved itself into a question of money. Such a cable as that which now connects France with England might, by proper arrangements and the aid of a number of steam-ships, be stretched across the Atlantic. The cost of the cable, with the expense of laying it down from the western coast of Ireland to New Brunswick, would not amount to one million pounds sterling; and for the accomplishment of a great national object, so important to commerce and to our colonial government, the expenditure of one million is scarcely worth consideration as an objection. But if the mode of communication which we have indicated as most suitable for submarine telegraphs were adopted, the cost would not amount to nearly so much, nor would the difficulty of laying down the wire be so great.

A single wire telegraph between England and America would, in the first instance at least, be amply sufficient. A thick galvanised iron wire or rod, coated with gutta-percha, and that coating protected for some distance by a covering of iron wire, might be constructed at a comparatively small cost, and would be much stronger and form a more efficient conductor of electricity than a thin copper wire. Such a telegraph-wire might be laid down between the west of Ireland and America for *less than* 100,000*l.* It should be remembered, also, that in the depths of the Atlantic, beyond the range of animal or vegetable life, and where no anchors ever reach, the telegraphic wire would be free from the dangers to which it is exposed in shallower seas. There is, indeed, no practical difficulty in extending a telegraph wire to America that may not be easily surmounted ; and with the almost certain prospect of instantaneous communication between the old and new world, for one-tenth the cost of building a bridge across the Thames, it cannot be long before that event is realised.

The extent of telegraphic communication in Great Britain at the present time is about 3000 miles, in France 2000, Prussia 4000, Austria 3000, and in America not less than 15,000.

CHAPTER XIX.

ELECTRIC TELEGRAPHS—SIGNAL INSTRUMENTS.

Progress of telegraphic invention—Instruments invented by Lomond, Reizen, Soemmering, Ronalds, Ampère, Schilling, Gauss, Steinhil, Alexander, Davy—Cooke and Wheatstone's needle telegraphs—Action of the needle telegraph—Rapidity of transmission—Henley's Magneto-Electric Telegraph—Breguet's Semaphore.

THE form of instrument first contrived by Lesarge, in 1774, for transmitting telegraphic messages has been already noticed. In 1787 M. Lomond so far simplified the means of telegraphic communications, as to point out the way of transmitting signals with a single wire. He adopted Lesarge's plan of using a pith-ball electrometer ; and he indicated the letters of the alphabet by the numbers, and the variations in the duration, of the divergences of the balls. With this telegraph M. Lomond communicated between different rooms in his house, the force employed being that of an electrical machine.

Ten years afterwards a very ingenious application of electric light to telegraphic purposes was made by M. Reizen. He pasted on a pane of glass strips of tin-foil with spaces cut out in the form of letters of the alphabet, so that when an electric spark was transmitted through the convoluted foil, the light at the interstices presented the form of the letter to be indicated. As a means of indicating the signals this mode was perfect, but it required a separate wire for each letter. Several other ingenious contrivances were invented on the continent for the transmission of signals by frictional electricity at the commencement of the present century, but none that deserve special notice in this summary.

The first known application of voltaic electricity for the transmission

of signals was that of M. Soemmering, in 1809, as announced to the Academy of Sciences of Munich. The bubbles of gas arising from the decomposition of water served to indicate the letters to be transmitted. Thirty-five gold wires were inserted through the bottom of a long narrow glass vessel, half filled with acidulated water. The circuit of the voltaic battery was passed through the water by connecting any two of the wires with the opposite poles of the battery. The instant that connexion was made and the circuit completed, bubbles of hydrogen gas rose from one of the wires, and of oxygen from the other. The hydrogen gas, being in the proportion of twice the volume of the oxygen gas, could be easily distinguished. Every wire signified a letter of the alphabet, and that wire from which the hydrogen was successively evolved was the letter to be noticed. By this means a very efficient mode of signalling by electro-chemical decomposition was arranged; but the practical difficulty of requiring so many wires would, under even more favourable circumstances, have prevented its adoption. By a simple modification of the instrument, however, it may be easily adapted to the transmission of all required signals with a single wire. If two gold wires only were inserted through the bottom of the glass vessel, the hydrogen gas might be made to issue from one or the other by reversing the poles of the battery, in the manner now done with the needle telegraph, as will be presently explained. By this means the issue of hydrogen gas from the right-hand wire might signify one letter, and from the left wire another. A repetition of the jets of gas, from either of the wires alternately, might signify other letters; and thus the whole alphabet might be indicated by a single circuit, in the same manner, and almost with equal facility, as it is now done, by deflecting a magnetic needle to the right hand and to the left. To call attention when a message was to be transmitted, M. Soemmering proposed to liberate a wound-up alarum by means of the evolution of the gas.

A modification of M. Soemmering's telegraph, by which all the signals might be transmitted with two voltaic circuits, was, indeed, proposed by M. Schwieger. By his plan the variations of the symbols were caused by employing two batteries of different powers, which consequently evolved different quantities of gas, and also by making varied intervals in the emissions of the gas from the gold wires.

A very remarkable form of electric telegraph was invented by Mr. Ronalds in 1818, in which, however, he reverted to frictional electricity for the actuating agent. At each corresponding station he had a revolving dial carried round by the seconds-hand of a clock. On this dial the letters of the alphabet were marked, and they were seen in succession through a small aperture, near to which was suspended a pith-ball electrometer. The two dials were made to revolve exactly together, so that when a letter appeared at one aperture the same letter appeared also at the aperture on the corresponding dial. The pith-balls were maintained in a diverging condition during the transmission of a message; and the instant that the letter required to be indicated came in sight at the transmitting station, the electricity sent through the communicating wire was discharged, and the collapse of the pith-balls directed the attention of the observer to it at the receiving station. In this manner communications could be transmitted with a single wire. The synchronous movement of the two clocks, to ensure the same letters appearing at the same time at each instrument, was obtained by adjusting them by an electric signal before each message.

Mr. Ronalds was very persevering in his attempts to perfect his telegraph, and to bring into notice the advantages of electricity as a means of telegraphic communication. He, at great expense, insulated eight miles of wire in glass tubes on the lawn of his house at Hammersmith, through which the telegraph was worked. He endeavoured to direct the attention of the government to the subject; but he met rebuff instead of encouragement. The government officials told him that *telegraphs are of no use in time of peace*, and that the semaphore answered all the required purposes! It is in this manner that attempts at improvement are generally received by persons in authority. They will not give themselves the trouble to investigate the merits of any invention, but wait until it has struggled through all difficulties, and forces itself on their notice. Of the very many useful inventions that are lost in the struggle which inventors have to make, little or nothing is known. In the case of Mr. Ronalds, finding his endeavours to be hopeless, he not long afterwards quitted England, and took no further steps to improve a system then considered by the government of so little value, but which is now, year by year, becoming of more and more importance as means of general communication.

The discovery of electro-magnetism by Professor Œrsted presented a new means of transmitting signals by voltaic electricity; and in 1820 M. Ampère laid before the Academy of Sciences a method which he had contrived for sending messages by the deflection of magnetic needles surrounded by coils of wire; his plan, however, required a separate wire for each symbol.

The Baron de Schilling made a great practical improvement on the plan of Ampère. He first constructed, at St. Petersburgh, in 1832, a telegraph in which five magnetic needles were employed. By the single deflection of these five needles alternately to the right or to the left, ten primary signals were obtained, without the necessity of two needles being used at the same time. The combination of a few such signals was made to express whole words or sentences. He also invented an alarum. The motion of one of the magnetic needles allowed a weight to fall, and sound an alarm. Another of Baron Schilling's plans, of a later date, was to use only one magnetic needle; and by counting the deflections to the right or to the left, the letters of the alphabet were indicated.*

Not long after the discovery of magneto-electricity by Professor Faraday, Messrs. Gauss and Weber of Gottingen applied the magneto-electric machine to the transmission of messages. They employed only a single needle to make all the symbols, and a telegraph operating on that principle was worked at Gottingen for a distance of a mile and a quarter.

Dr. Steinheil's telegraph, invented in 1837, presented great advancement in the application of electricity to telegraphic purposes. It is spoken of by Mr. Highton as a perfect arrangement, and as one which "may well put to shame many of the plans afterwards patented in this kingdom." Dr. Steinheil could either transmit messages by sound or by making permanent marks on paper. This telegraph consisted of a single circuit, half of it being galvanised wire, the other half the earth, and the stations between which the telegraph worked were twelve miles apart. One or two magnetic needles were employed as required, and they were deflected by

* The Electric Telegraph, by E. Highton.

magneto-electricity. When it was required to telegraph by sound, the needles struck against either of two bells differently toned. When the message was recorded, the needles were furnished with small tubes holding ink, and by their motions dots were made on paper properly moved in front of them by wound-up mechanism, one needle making dots in one line, and the other needle making dots in a line underneath the former. Not more than four dots were required to make any of the letters, and some were marked by a single dot. The mode of recording on paper the messages transmitted by this means will be rendered more intelligible by the annexed representation of the symbolical alphabet made by the pen-holding needles.

fig. 81.

Before the year 1837 scarcely any attempt besides that of Mr. Ronalds's had been made in England to improve the electric telegraph; but that year seems to mark the commencement of the direction of inventive genius to the subject in this country, which has since progressed most rapidly. In June 1837 the electric telegraphs of Mr. Alexander and of Mr. Davy were publicly exhibited in London. The former operated by removing screens from before letters of the alphabet. The letters were painted on a frame, and were concealed from sight by small light screens attached to the magnetised needles, the deflection of which, when the voltaic current passed through the coils, successively exposed the letters to view. Mr. Davy's telegraph was constructed on the same principles, but the letters were painted on ground glass illuminated from behind, consequently the letters were more distinguishable. Both these telegraphs required a separate voltaic circuit for each symbol. It is, indeed, curious to notice in the progress of telegraphic invention, that notwithstanding the impracticability of using a telegraph which required so great a number of wires, notwithstanding also that the mode of transmission by one or two wires had been often pointed out, how resolutely each inventor in succession adhered to the appropriation of a separate wire for every symbol to be transmitted.

In 1837, Professor Wheatstone, who, in conjunction with Mr. Cooke, succeeded in establishing the first working electric telegraph, appeared in the field. The patent taken out by Messrs. Cooke and Wheatstone in 1837 was for a needle telegraph, in which the symbols were made with five needles. In the following year the arrangement was simplified so far as to reduce the number of needles to two. That arrangement of the double needle telegraph is the one that continues to be generally used in this country.

It would occupy far too much space to give an account of all the modifications and improvements in the modes of transmitting messages that have been since introduced. Upwards of fifty patents for electric telegraphs have been obtained in England since the first of Messrs. Cooke and Wheatstone's, and numerous other similar inventions have been patented on the continent and in America; but it will be sufficient to limit our notice to those that possess the most distinguishing features.

The needle telegraph is simply a delicate galvanometer constructed of numerous coils of the finest copper wire covered with silk. The magnetised needle is placed upright, the lower end being slightly heavier, to make it assume a perpendicular position when in its normal state. There are two oblong coils of the fine wire connected together, between which the needle is poised. The object of employing two connected coils instead of a single one, is to allow the axis that carries the needle to pass between.

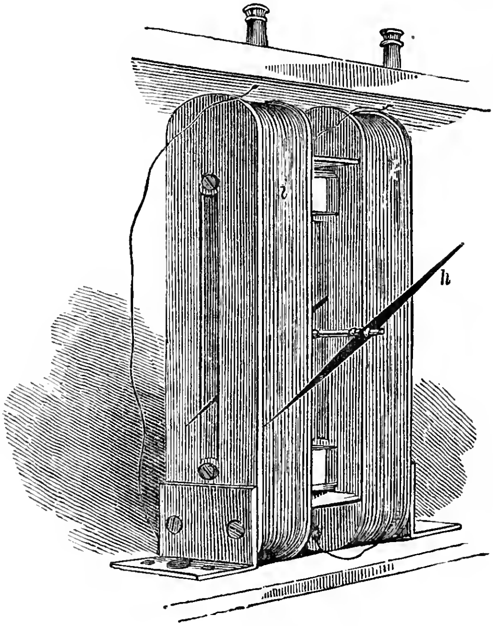


fig. 82.

The diagram exhibits a perspective view of a mounted needle *h*. The axis is supported within the coil *i k*, so as to allow the needle to vibrate with the least possible resistance from friction. The needle *h* is fixed to the end of the axis, and is outside the coil, to serve as an index to denote the deflection of the needle. The poles of the outer needle are in a reversed position to those of the inner one, so that the magnetic action of the coil, when the current passes, tends to deflect them both in the same direction and with increased force. The index is, however, sometimes made of a light strip of wood, but by that means some of the power of the coil is lost. When the voltaic current is sent through the coils the needle is instantly deflected either to the right or to the left, according to the direction in which the current passes; the connexions with the copper and the zinc ends of the battery being so arranged that they may be reversed on moving the working handle either to the right or to the left.

The arrangements of the instrument to reverse the directions of the voltaic current are rather complicated; but the principle on which they depend will be readily understood by inspection of fig. 83. The letters D E

represent the communicating wire, in which there is a break at the transmitting station. Close to this break is placed a movable piece *b d*, that slides laterally, and it is connected with the two poles *c z* of the voltaic battery. The upright wires at *b d*, each connected with the zinc pole *z*, are insulated from the wire *e*, which is connected with the copper pole *c*. It will be evident, therefore, that if the piece to which these wires are attached be shifted towards the right, the wire *e* will touch the communicating wire at D, and *b* will touch E. By these contacts with the two ends of the communicating wire, the circuit of the voltaic battery will be completed, and an electric current will be transmitted from *c* to D, in the direction of the arrow, to the earth-plate H, thence to the receiving station, and back again, through the instrument I, to the zinc pole *z*. The lateral movement of the wires connected with the battery to the left will, in the like manner, bring *e*, which is in connection with the copper pole, to E, and *d* of the zinc pole to D, and the current will then be sent in the opposite direction, viz. from the copper pole of the battery to E, through the instrument I to the receiving station; and it will return by the earth-plate H to the zinc end of the battery. By rapidly changing the positions of the wires from side to side, the voltaic current may be thus reversed several times in one second; and each reversal of the current will change the direction in which the needle is deflected.

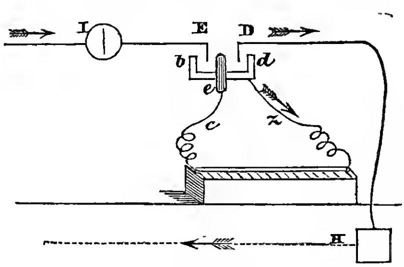


fig. 83.

By the adoption of what is called a code of signals, the deflections of a single needle may be made to denote all the letters of the alphabet. The code at present in use in this country for a single needle-telegraph is shewn in the annexed diagram; the number of deflections of the needle to the right and left being made to indicate the letters under which the marks are placed. The deflections of the symbols for each letter commence in the direction of the short marks, and end with the long ones. Thus it will be seen, that to indicate the letter D the needle is first deflected once to the right and then once to the left; whilst two deflections, beginning with one to the left and ending with one to the right, signify the letter R.

It will be observed that all the symbols in the left division of the scale commence with a right-hand deflection and end with the left; whilst those on the right division commence with the left and end with a deflection to the right. When the double needle-telegraph is used, the number of successive deflections requisite to denote all the letters of the alphabet are fewer, because, with two needles capable of being

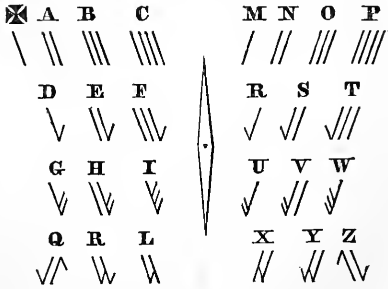


fig. 84.

pointed in both directions, six primary symbols are obtained by a combination of the deflections of the two needles.

A practical knowledge of the working of the needle instruments is generally acquired within a month. Some of the telegraph clerks have become so expert by continued practice, that they can transmit as many as 150 letters a minute with the double needle instrument. It is, however, much more difficult to read the symbols than to transmit them; and as the messages must be written down, the rapidity of transmission is practically limited to the speed of writing, which seldom exceeds 100 letters a minute, and that is considerably faster than the average rate of transmission.

In the early stages of the progress of the electric telegraph it was considered very important to have the means of calling attention when a message was to be transmitted, and there were many contrivances for ringing bells at the distant stations. The use of alarums has, however, been discontinued at nearly all the stations of the Electric Telegraph Company. The sound of the needles striking against the pins fixed in the dial to limit the range of the deflections is generally sufficient to call the attention of the clerks, who are constantly seated near their instruments. When alarums are required, bells are sounded by liberating a wound-up mechanism by withdrawing a detent by means of an electro-magnet.

Fig. 85 represents a front view of a double needle instrument. The handles are held by the clerks, and by moving one or both to the right or to the left one or both of the needles are correspondingly deflected. In transmitting messages in this manner it is customary for the clerk at the receiving instrument to intimate at the end of each word that he understands, by giving a single deflection of the left-hand needle to the right; when he does not understand, and requires the word to be repeated, he deflects the same needle to the left.

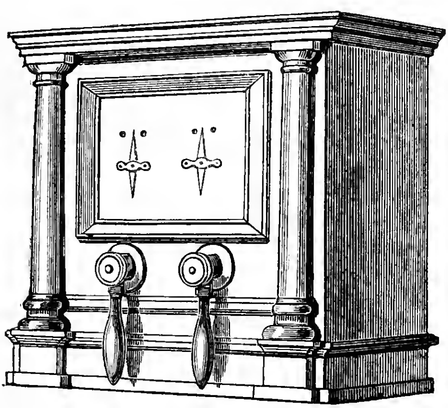


fig. 85.

There have been many patents obtained for modifications of the needle telegraph; but they are all identical in principle with the original one of Messrs. Cooke and Wheatstone. One of the objects that it has been the endeavour to attain, is a dead beat of the needle without any vibration. It is now the practice to use a piece of lozenge-shaped magnetised steel instead of a needle within the coil, that form having been found to be more sensitive to the action of the voltaic current, and to produce less vibration.

One arrangement of the needle telegraph, quite distinct from the foregoing, is the magneto-electric telegraph invented by Mr. Henley. We have already noticed several attempts to apply magneto-electricity to telegraphic purposes, but that of Mr. Henley is by far the most successful. Two armatures, in close proximity to strong permanent magnets, are made

to revolve rapidly by striking down projecting levers; and the revolutions of the armatures induce currents of electricity along the communicating wires, that re-act on the magnetic needles, and cause them to be instantly deflected.

The electricity generated in this manner is small in quantity, and of comparatively great intensity, therefore more liable to be diverted from the circuit by imperfect insulation. Another difficulty which this form of telegraph has to contend with is, that the current cannot be conveniently reversed, therefore each needle is only deflected in one direction. Two communicating wires are consequently required to obtain the same combination of deflections that can be given with a single wire when a voltaic current is transmitted. It is a great advantage of this system that it dispenses with the use of voltaic batteries, which are very troublesome and expensive; and it remains a question to be determined by practical experience, whether this advantage is sufficient to counterbalance the objections attending the use of the magneto-electric telegraph.

The electric telegraph used on all the telegraph lines in France was invented by M. Breguet, and transmits symbols resembling those of the semaphore. Two movable arms attached to the tops of two stationary vertical pillars are made to assume positions at certain angles in the circles they describe, and the combinations of those different positions in the two arms allow of their expressing a great variety of symbols, which correspond exactly with the code of the discarded semaphore.

We have heard this kind of signal telegraph highly commended, and have seen messages that were transmitted by it at the rate of 120 letters a minute. It possesses the advantage, from the great variety of combinations of which it is capable, of not requiring successive actions to indicate any letter of the alphabet or numeral. The movements are effected by electro-magnets, which give rotary motion to wheels that carry round the arms; and the accuracy with which it is necessary that the semaphore should be pointed to the required angles renders very nice adjustment of the instruments indispensable.

CHAPTER XX.

ELECTRIC TELEGRAPHS—RECORDING INSTRUMENTS.

Morse's telegraph—Modification of it by the Electric Telegraph Company—Bain's dotting telegraph—Brett's printing telegraph—Copying telegraph—Mode of transmitting copies of writing—Regulation of the instruments—Rapidity of the copying process—Means of maintaining secrecy.

The telegraphic instruments we are now about to describe record on paper the messages they transmit; in other telegraphs the symbols are exhibited for an instant and disappear. Many more errors occur in reading the evanescent signals than in the transmission of them; but as the recording instruments impress what is transmitted, the message may be read at leisure when the whole is completed.

We have already noticed, in the progress of telegraphic invention, the recording telegraph of Dr. Steinheil, which made dots on paper by means of ink-holders fixed to magnetic needles. That plan, though it has formed the model of several subsequent inventions, was imperfect, because the deflections of the needles were retarded by the weight of the pens, and the marks made were not sufficiently distinct.

The most successful of the instruments that impress arbitrary symbols on paper is that of Professor Morse of America, invented in 1837, and since considerably improved. The transmitting part of the instrument is of the very simplest kind, and might be carried in the waistcoat-pocket. It consists only of a key, like the key of a musical instrument, which, on being pressed down, makes connexion with the voltaic battery for a shorter or longer duration, according to the time that the finger of the operator is pressed upon it. The receiving instrument is more complicated. By means of clock mechanism, a small drum, round which a long strip or ribbon of paper is rolled, is made to revolve. The paper as it is unrolled from the drum passes under a lever attached to the keeper of an electro-magnet, armed with a projecting point. When the electro-magnet is put into action, the lever is drawn down on the paper, and the point makes an indentation on it. As the paper is continually drawn along, the length of the indentation varies from a mere dot to a long stroke, according to the time that the lever continues to be pressed against the paper; and by varying the duration of the pressure on the transmitting key, dots and strokes are impressed on the paper at the receiving station. Conventional symbolical alphabets have been arranged, by the alternation of the dots and strokes, which, with a little practice, may be easily read. The symbolical alphabet that has been adopted in this country, when a modification of Morse's system is used, is represented in figure 86.

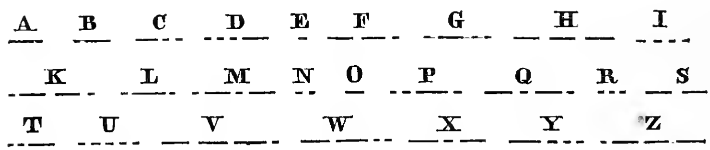


fig. 86.

As the mechanical power required to impress marks on the paper is stronger than could well be transmitted directly through the long circuit, a local voltaic battery and magnet are employed to do the work; and they are brought into action by means of a small electro-magnet, surrounded by a great number of convolutions of very fine wire, that may be actuated by the feeble current transmitted by the communicating wire. This kind of telegraph is extensively used in the United States, and it is also coming into use in Belgium and Germany.

In the modification of Professor Morse's instruments, as occasionally used by the Electric Telegraph Company, the marks on the paper are made by the agency of electro-chemical decomposition, and not by mechanical pressure. The application of electro-chemical decomposition to telegraphic purposes was first adopted by Mr. Davy in 1838. His plan

was to moisten paper in a diluted solution of nitric acid and prussiate of potass, and to send a voltaic current from the positive pole of the battery through a steel wire pressing on the paper. By the action of electricity the oxygen of the acid attacks the steel wire, and a deposition of iron is made on the paper, and it is converted into prussian blue by the prussiate of potass. The arrangements of Mr. Davy's recording telegraph need not be described, as they were never made practically available; but his system of marking paper by electro-chemical agency has been successfully applied to other telegraphs.

In 1846, Mr. Bain contrived a modification of Professor Morse's system, in which the marks are made by Mr. Davy's process. The transmission of symbols in this telegraph of Mr. Bain's is not effected by a key moved by hand, but metallic contact is made and broken by mechanical means. Apertures are punched in a strip of paper, to correspond with the dots and strokes intended to be impressed on the paper of the receiving instrument. The paper-message when thus prepared is passed rapidly over the periphery of a metal wheel, and a brass wire-spring, connected with a voltaic battery, presses on the paper as it passes along. The spring, by pressing through the holes, touches the wheel, which is connected with the other pole of the battery, and thus completes the voltaic circuit, which is again broken when the spring rests on the insulating paper. Mr. Davy's prepared paper is applied at the receiving station, and the effect of the action of the two corresponding instruments is to transmit dots and strokes, marked in prussian blue on the paper at the receiving station, agreeing with the smaller and larger holes punched in the strip passed through the transmitting instrument. The annexed diagram represents a piece of the punched paper with the symbols of the word "Bain."

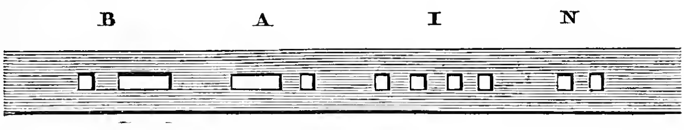


fig. 87.

The rapidity of transmission by this means exceeds that of any other telegraph. As many as 1000 letters a minute have been transmitted from London to Manchester; but the time required for punching the paper preparatory to sending a message is a serious drawback to the general use of the system.

The Electric Telegraph Company, when they employ any other instrument than the needle, use that of Professor Morse, with the substitution of electro-chemical marks for those produced by mechanical pressure. The rate at which messages can be transmitted by means of the key with a single communicating wire is about ninety letters a minute. The transmission, however, requires the utmost attention on the part of the operator, who cannot continue to transmit at that rate for many minutes at a time.

Among the early inventions of recording telegraphs were some that printed letters from metal types. Professor Wheatstone and Mr. Bain disputed for the honour of being the inventor of the first printing electric telegraph; but their instruments did not attain such a degree of perfection

as to render them practically useful. Mr. House of America, and subsequently Mr. Brett, have, however, succeeded in producing printing telegraphs which work effectively through long circuits. The mechanism is complicated, but the principle on which the action depends may be easily understood. A small wheel, that revolves by the agency of electro-magnetism, carries on its circumference metal types of each letter of the alphabet, which are inked as the wheel turns round by rubbing on the surface of a small inking roller. At one part of the circumference of the type-wheel there is a ribbon of paper close to the types, and by the pressure of the paper against the wheel the letter that is opposite to it is printed. The movement of the type-wheel is regulated by the operator at the transmitting instrument, who, by bringing an index to point on the dial of his instrument to the letter required, it at the same time causes the type-wheel to move round, so as to bring a corresponding letter opposite the paper. A local electro-magnet is then put in action; by which means the drum on which the paper rests is pressed against the type, and the letter is printed. As each letter is thus printed, the strip of paper is moved onward about a quarter of an inch, to leave a clear space for the next.

The action of the printing telegraph is rather slow; but it is worked with a single wire. We have not seen it working faster than at the rate of forty letters a minute; but we are informed that it can print upwards of sixty letters in that time. One peculiar advantage of Mr. Brett's arrangement is, that the type-wheel is placed in correct position at the end of each transmission; so that if by mistake an error is committed, by printing one letter instead of another, that error is not continued to the next letter, for the type-wheel is adjusted to start from zero before the next movement of the index. All preceding printing telegraphs were liable to perpetuate errors whenever a single one had been committed.

The copying-telegraph, of which the author of this work is the inventor, transmits copies of the handwriting of correspondents. The advantages of this mode of transmission are, that the communications may be authenticated by the recognised signatures of the parties by whom they are sent, and as the writing received is traced from the original message, there can be no errors of transmission; for every letter and mark made with the pen are transferred exactly to the other instrument, however distant.

The electro-chemical mode of marking the paper, invented by Mr. Davy, is adopted in the copying process. The writing is copied on paper soaked in a solution of prussiate of potass and muriatic acid, a piece of steel wire serving for the pen. The paper is placed round a cylinder about six inches in diameter, and a steel wire, connected with the copper end of the voltaic battery, presses upon it, and is carried slowly along by a screw as the cylinder revolves. By this arrangement, when the voltaic current passes uninterruptedly from the wire through the paper to the cylinder which is connected with the zinc end of the battery, lines are drawn upon it at the same distance apart as the threads of the screw that carry the point. These lines are in fact but one continuous spiral line, commencing at one end of the cylinder and ending at the other.

The communication to be transmitted is written on tin-foil, with a pen dipped in varnish. Thin sealing-wax varnish, made by dissolving

sealing-wax in spirits of wine, answers the purpose best, as it dries very quickly. The letters thus written form on the conducting metal surface a number of non-conducting marks, sufficient to interrupt the electric current, though the deposit of resinous matter is so slight as not to be perceptible by the touch.

The message on tin-foil is fixed round a cylinder at the transmitting instrument, which instrument is a counterpart in its mechanical arrangements of the receiving one, and either of them may be used to transmit and receive messages. A metal style in connexion with the voltaic battery presses on the tin-foil, and it is carried along by an endless screw as the cylinder revolves, exactly in the same manner as the steel wire that draws lines on the paper on the receiving instrument. The varnish writing, when it interposes between the style and the tin-foil, stops the electric current; consequently, at every part where the electric current is stopped by the varnish at one instrument, the steel wire ceases to make marks on the paper at the other station. Both instruments are so regulated that the cylinders rotate exactly together, therefore the successive breaks of the electric current by the varnish-letters cause corresponding gaps to be made in the lines on the paper; and the succession of these lines, with their successive gaps where the letters occur, produces on the paper of the receiving instrument the exact forms of the letters. The letters appear of a white or pale colour on a ground of blue lines, there being about nine or ten lines drawn by the wire to make one line of writing. In the diagram, A shews the writing on tin-foil, from which the copy is made in the form shewn at B.

A

B

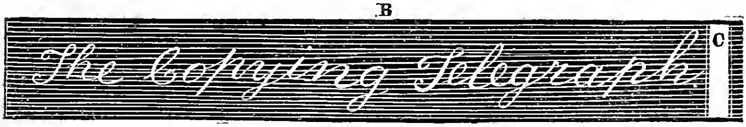


fig. 88.

It is essential to the correct working of the instruments that the cylinders should rotate exactly together. This synchronous movement of the two instruments is effected by means of regulating electro-magnets, aided by a "guide-line" on the transmitting cylinder.

The moving power of each instrument is gravity, accelerated motion being prevented by a rapidly revolving fan, which produces a very steady movement of the cylinder. The speed may thus be very easily varied by adding or by taking off weight. The "guide-line" consists simply of a strip of paper pasted across the tin-foil at a right angle, as shewn at C. That strip of paper effectually stops the electric current, and leaves a gap of equal breadth in each line drawn on the prepared paper of the receiving instrument. If the receiving instrument be moving at exactly the same speed as the transmitting one, these gaps in each line will be in the same relative

positions, and will fall under each other on the receiving cylinder, making a broad white stripe corresponding with the strip of paper on the transmitting cylinder. But if the receiving cylinder be moving faster than the other, the gaps in the lines will not fall under one another, but every one will be farther towards the right hand. By noticing the position of these gaps on the paper, it may be seen exactly how much faster one instrument is going than the other, and weight may be taken off the receiving instrument until the gaps form a continuous stripe. In this manner the two instruments may be regulated to move together. It is immaterial at what distance apart they are; for if they be in the same room, or two hundred miles from each other, the same plan of adjustment must be adopted.

Supposing the mechanism of the instruments to be very good, and that there were no irregularities on the surfaces of the cylinders, the plan of regulating by means of the guide-line alone would be sufficient for the copying process. Legible writing may, indeed, be obtained in that manner, but not with sufficient accuracy and certainty to be depended on in ordinary working operations. To secure the requisite degree of accuracy and certainty, an electro-magnetic regulator is used. This may be brought into action by means of a second communicating wire, or by local action altogether; in the latter case a single wire only is required to work the copying telegraph. When two wires are employed, one of them is used for the electro-magnet that regulates the instruments, the other for transmitting the current that marks the paper by electro-chemical decomposition. The diagram will assist in explaining the mode of regulating the instruments when a separate wire is used for that purpose.

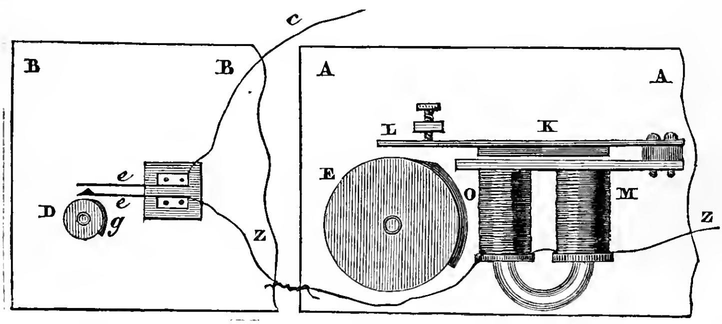


fig. 89.

A side view only of the two instruments is given, without their stands or other mechanism than that which appears on the outside of each; the trains of wheels propelled by the weights being contained within the cheeks A A and B B, and the cylinders being on the opposite sides. The wheel D is fixed to the projecting arbor of a fast-moving wheel next to the fan, and it makes twelve revolutions to one of the cylinder. Two springs *e e*, insulated from the instruments by being mounted on wood, are connected by wires *c* z to the voltaic battery, and to the electro-magnet M on the other instrument. The other end of the coil of wire round the electro-magnet is fixed to the voltaic battery, so that when the two springs *e e* touch, the circuit of the battery is completed, and the electro-magnet is

instantly brought into action. This occurs once every revolution of the wheel D, by the projecting part g pressing the two springs together. The wheel E on the instrument A is fixed on to the arbor of a wheel corresponding with that of D, and likewise makes twelve revolutions to one revolution of the cylinder.

The keeper K of the electro-magnet has an arm or lever L added to it, which reaches to the circumference of the wheel E, and, when the keeper is attracted by the magnet, rubs against a projecting part of the circumference O, and thus operates as a break to check the motion of the instrument. In regulating the instruments to rotate synchronously by these means, a heavier weight is put on A than on B, to cause it to rotate considerably faster than the other when the break is not applied. But when both instruments are set in motion, the lever being pulled down each time that the springs are pressed together by the wheel D, the break is thus put in operation just sufficiently to make the movements of the two instruments correspond. By this arrangement it will be observed that one instrument regulates the other; and it has it under such complete control, that if the speed of B be diminished, the movement of A will be retarded by the longer continued action of the break, and be made to rotate equally slowly, and even to stop by stopping the motion of B.

When the instruments are worked at a distance from each other, the electro-magnet M is put into action by a local battery, and the contact is made and broken by an intermediate small electro-magnet, as in Mr. Morse's telegraph. In that manner the copying telegraph has transmitted messages with perfect accuracy from Brighton to London.

When a single communicating wire only is used, the instruments are regulated independently of each other by means of pendulums. Clock-movements, with pendulums that beat four times in a second, are employed at each instrument. These pendulums at every vibration strike against springs, at each contact with which the electro-magnets which regulate the instruments are brought into action.

The arrangement of the mode of making and breaking contact by the pendulum will be easily understood by the diagram. The pendulum D is

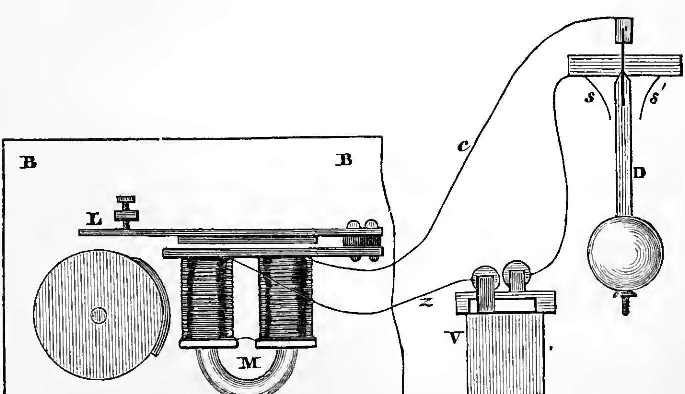


fig. 90.

connected by the wire *c* to the electro-magnet M. The springs *s s'* are connected with the voltaic battery V, from which a wire *z* connects with the other end of the coil of the electro-magnet. It will be evident, therefore, that when the rod of the pendulum vibrates against *s s'*, the voltaic circuit is completed through the magnet, which is brought into action in regulating the instruments as rapidly as the pendulum beats. Each instrument has its regulating magnet and pendulum, and the regulation of each is thus effected independently, without requiring a second wire.

The guide-line serves to indicate with the greatest accuracy whether the pendulums at two corresponding stations are beating together; for if one be vibrating faster than the other, the guide-line on the paper will be slanting instead of perpendicular; and by means of an adjusting screw to raise or lower the pendulum-bob, the two may be readily adjusted to beat together. In this manner a variation of even the thousandth part of a second may be observed and corrected.

It may probably be supposed, because the metal style has to pass over each line of writing nine or ten times to complete it, that the copying process must be necessarily slow; but it is, on the contrary, the quickest mode of transmission yet invented, with the exception of Mr. Bain's. A cylinder six inches in diameter will hold a length of paper on which one hundred letters of the alphabet may be written in a line. When the instruments are working at their ordinary speed, the cylinder revolves thirty times in a minute; and allowing ten revolutions to complete each line of writing, the rate of transmission is three hundred letters in a minute. Much greater speed than that has been obtained; and there is, indeed, no limit to the rapidity of transmission other than the diminishing strength of the mark on the paper when the decomposition is extended over a larger surface.

One of the advantages which the copying process also possesses is the means it affords of maintaining the secrecy of correspondence. It is now customary for those who wish their communications not to be known to transmit messages in cypher, by which certain letters or figures have significations given to them which are only intelligible to the parties corresponding. This plan has the serious disadvantage of being very liable to error, because the clerks engaged in transmitting such a message are purposely kept in ignorance of the meaning of the symbols they transmit. By the copying telegraph whatever symbols are made on the tin-foil are transmitted as accurately as if written in full, for no manipulation whatever is required, the effect being produced altogether by mechanism.

There is also a special mode of maintaining secrecy by transmitting the messages impressed on the paper invisibly. If the paper be moistened with diluted acid alone, the iron is deposited on the paper, but no mark whatever is visible, and the paper remains blank until it is brushed over with a solution of prussiate of potash, which instantly renders it legible. In this manner messages written with colourless varnish may be transmitted without any one seeing the contents; that part where the name and address are written being alone rendered legible till the message is delivered to the person for whom it is intended.

The author trusts he shall be excused for having described thus fully his invention of the copying telegraph. It is very probable that he attaches more importance to it than those not so specially interested may

think that it deserves; but he has received the assurance of some scientific gentlemen who have been the longest and the most successfully engaged in such undertakings, that the copying of writing is the *beau-ideal* of telegraphic communication, and that sooner or later it must supersede all other means of corresponding by electric telegraph.

CHAPTER XXI.

ELECTRO-METALLURGY.

Competing claims to the discovery—Deposition of medals from their solutions—Its dependence on secondary results—Apparent anomaly of deposition in a single cell—Formation of moulds—Copying medals—Reduplication of copper-plate engravings—Glyphography—Electro-plating and gilding.

The important application of electricity to working in metals is of even more recent date than the invention of the electric telegraph. The fact that metals could be "revived" from their solutions by means of electricity was, indeed, known at the beginning of the present century. In 1805 Brugnatelli gilded a large silver medal by connecting it with the negative pole of a voltaic battery, and then immersing it in a solution of ammoniuret of gold; but, strange as we now think it, the practical use to which this peculiar action of electricity might be applied did not occur to him. Mr. Spencer of Liverpool claims to be the first who discovered that the deposition of metals by electrical agency might be rendered useful in the arts. He states, that when experimenting in 1837 with a Daniell's battery, he used a penny instead of a plain piece of copper for a pole; and that on removing the wire which connected the penny with the battery, he pulled off a portion of the deposited copper, which he found to be impressed with a counterpart of the head and letters of the coin. Even this did not suggest to Mr. Spencer any useful application, until he accidentally dropped some varnish on a piece of copper similarly connected with the negative pole, and he observed that no deposition of copper took place on those parts covered by the varnish. It then occurred to him that by covering a sheet of copper with varnish or wax, and cutting a design through it so as to lay bare the metal, the copper would be deposited from the solution of sulphate of copper in the lines of the design cut through the wax, and would adhere to the surface of the plate, producing the figure in relief.

The statement of the experiments by Mr. Spencer was not made known until 1839, after Professor Jacobi of St. Petersburgh was announced to have made a similar discovery. Indeed, before the account of Mr. Spencer's experiments was published, a letter from Mr. Jordan, a printer, appeared in the *Mechanics' Magazine* of May 11th, 1839, describing a method of producing copper casts by what is now known as the electrotype process. It appears, therefore, that though Mr. Spencer was the first discoverer, the earliest published notice referred to the discovery of Jacobi, whilst the letter of Mr. Jordan contained the first explanation of the mode

by which the effects may be produced. It was not, however, till the autumn of the same year, when Mr. Spencer brought the subject before the British Association for the Advancement of Science, and exhibited numerous specimens of electrotype casts and designs, that the attention of the public was directed to this application of electric force.

It is well observed by Mr. Napier, in his excellent treatise on electro-metallurgy, to which we are much indebted, "In reviewing the rise and progress of any discovery in the arts and sciences, particularly of one connected with chemistry, there are two circumstances which almost invariably demand especial notice. The first is, that the discovery has been the result of accidental observation rather than the result of a direct endeavour to make the discovery. The second is, that after the discovery has been made known, it is found that many previously published experiments exhibited results which bore more or less directly upon the subsequent discovery, and which are consequently sometimes cited to detract from the merit of the discoverer, and the originality and value of his discovery." These remarks apply with special force to the art of electro-metallurgy. It is to Mr. Spencer, however, that we are inclined to award the honour of the discovery, and the merit of having brought it into practical operation in this country.

The deposition of metals in the process of electro-metallurgy has been previously explained to be the result of secondary action, arising primarily from the decomposition of water in the fluid menstruum.

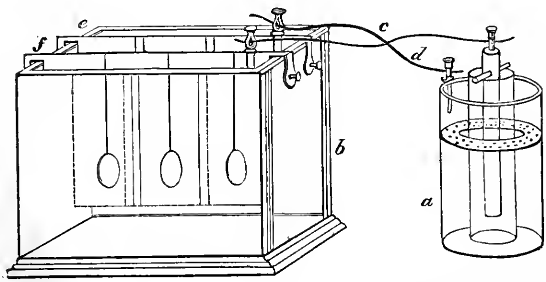


fig. 91.

Let *b* be a vessel containing a saturated solution of sulphate of copper (blue vitriol), with three circular medals immersed in it and connected with the voltaic battery *a* by the wires *c d*, from the copper and zinc plates respectively. An electric current will thus be established from *d*, which is in connexion with the copper of the battery, to *b*, and the oxygen of the fluid decomposed will be liberated on the surface of the copper plate *e*, to which it is attached, and the hydrogen on the medals. But the nascent hydrogen, the instant that it is liberated from its association with oxygen in the fluid, and before it can assume a gaseous form, combines with the oxygen that holds the copper in solution, and with it constitutes another particle of water, and the copper is deposited on the medals.

The deposition of the metal from its solution is the result of a variety of rather complicated chemical actions. The strong affinity of oxygen for the hydrogen, with which it was combined to form water, is first overcome

by the influence of the electric force. The oxygen, liberated at the plate *e*, immediately enters into combination with the sulphur in the solution to form a fresh particle of sulphuric acid; the hydrogen, freed from its combination with oxygen, is transferred to the medals, and its affinity for oxygen being greater than that subsisting between the oxygen and the copper held in solution, the hydrogen re-enters into combination with oxygen and forms a fresh particle of water, whilst the copper is set free in its metallic state and is deposited. In all the processes of electro-metallurgy, whether they consist in the depositions of copper or of other metals from their solutions, the same chemical actions and reactions take place; the hydrogen in every case effects the deposition of the metal by combining with the oxygen which holds the metal in solution at one pole of the battery, after having been separated from an equal particle of oxygen at the positive pole. There is, consequently, throughout the process a continual decomposition of water at one pole of the voltaic battery, and a recomposition of exactly the same quantity of water at the other pole.

One of the simplest illustrations of metallic deposition by electro-chemical action is afforded by the following experiment. Put a silver spoon A, fig. 92, into a glass containing a solution of sulphate of copper, and into the same glass insert a piece of zinc Z. No change will take place in either metal so long as they are kept apart, but as soon as they touch, copper will be deposited on the spoon, and if it be allowed to remain, the part immersed will be completely coated with copper, which will adhere so firmly that mere rubbing alone will not remove it. The same effect takes place, if instead of bringing the metals into contact in the solution, they are connected externally by the wire *c*.

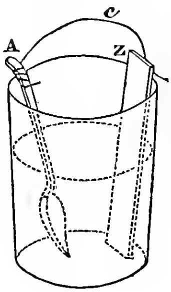


fig. 92.

The foregoing experiment represents the electrotype process as carried on in a single cell, the metal surface whereon the copper is deposited then forming the conducting plate of the voltaic arrangement by which the electricity is generated. It must be observed that, in this single-cell arrangement, the deposition takes place on the conducting plate; whereas, when the operation is conducted in a separate cell, it is on the plate connected with the zinc that the deposition occurs. In order to explain this apparent anomaly, let it be remembered that the metal is always deposited from its solution on the surface *into* which the electric current enters, and that that is the negative pole of the battery. The electricity excited by the zinc passes through the fluid and enters into the conducting plate; therefore, when the deposition takes place in the same cell, the metal is deposited on that surface; but when the electric current is transmitted through a wire into a separate cell, it then proceeds *from* the conducting plate, that wire becomes the positive pole of the battery, and when introduced into the decomposing cell, the electric current passes from it to the metal surface connected with the other, or negative pole, on which accordingly the deposit takes place.

Having, we trust, made the *rationale* of the electrotype process intelligible, it is only necessary to give a general explanation of the modes of operating. Those who desire to pursue the art practically will do well to

consult the able and compendious treatises on this subject by Mr. Napier, Mr. Smee, and by Mr. C. V. Walker.

The first application of the electrotype process was to copying ancient coins and medals, and that continues to be the principal use to which it is applied by amateurs. To obtain a fac-simile of a medal, it is necessary in the first place to make a mould, to serve as a matrix for the copper to be deposited upon. This may be done, when circumstances will permit, by obtaining an electrotype directly from the surface of the medal. To do this, the surface whereon the deposition is to take place must be well cleaned, and afterwards smeared over with a minute quantity of sweet oil or with black lead, which is requisite to prevent the deposited copper from adhering. The thinnest possible film of oil should be allowed to remain, and even after the medal has been rubbed with dry cotton-wool, sufficient will adhere to effect separation from the deposit. It is evident that only one face of the medal can be copied at a time, therefore the side not to be operated on must be protected by a covering of wax. The preparation of the medal is completed by twisting a fine wire round the edge for the purpose of suspending it in the copper solution, and of connecting it with a piece of amalgamated zinc.

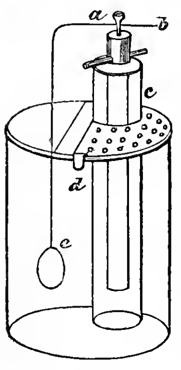


fig. 93.

The decomposing apparatus may consist of a large preserve jar, fig. 93, to hold the solution of sulphate of copper, and a porous vessel *c* placed within the jar to contain the zinc. Fill the porous vessel to within a few inches of the top with a mixture of sulphuric acid and water, in the proportion of one of acid to twenty-four of water, taking care that the solution in the jar and the acidulated water in the porous vessel are nearly on the same level. The medal *e* suspended by the wire is then immersed in the jar, and is connected with the zinc in the porous vessel by the wire *a b*, as shewn in the diagram.

This arrangement may be considered as equivalent to a single cell of a Daniell's battery, in which the medal represents the conducting plate. The electric action is established as soon as the zinc and the copper are immersed; the deposition of the copper on the medal immediately begins, and it is continued as long as the action is maintained. In twenty-four hours the deposited copper will be about the thickness of a card, which is quite sufficient. This coating of copper may be easily separated from the medal, and will be found to present an exact counterpart of it, those parts in relief on the medal being of course presented as sunk in. The mould thus formed is to be treated exactly as the medal, and the copper will be deposited in it, so that when removed the electrotype will be a fac-simile of the medal, with the intaglio and relief corresponding with the original. A mould of this kind will, with care, serve to take many copies.

A mould made by depositing the copper on the surface is more sharp in its details than moulds taken by other means; but in many cases, especially with ancient coins, the surfaces cannot be cleaned so as to allow of this mode being adopted, and other means of making the moulds must be found. One of the best plans is to make a cast of the original in fusible metal. A strip of tin is bound round the edge of the coin, about a quarter of an inch higher than the highest part. The metal is melted and

poured into a small wooden tray, and when cooled into a semi-fluid state, the coin is suddenly pressed upon it and held down till the metal "sets." The fusible metal is made by melting and mixing together tin, lead, and bismuth, in the proportions of two of the latter to one each of the former metals. This alloy melts at a temperature below that of boiling water, therefore it affords great facility for removing the moulds from the deposits in case they should adhere.

Wax, plaster of Paris, and gutta-percha, are frequently employed for making moulds, especially for large objects. When such substances form the moulds, it is necessary to cover their surfaces with black-lead, bronze-powder, or other conductors of electricity. The discovery that plumbago will impart a sufficiently good conducting surface to objects that are otherwise incapable of receiving metallic deposits, has afforded great facility in extending the electrotype process. Flowers, leaves, lace, and even insects, may be thus coated with a thin protecting film of metal, which preserves their forms accurately and durably.

A recent valuable application of the electrotype process is the coating of glass and earthenware vessels, which are thus rendered fire-proof; for the metallic coating quickly distributes the heat equally over the surface, and thus prevents them from breaking, as they otherwise would, by unequal expansion. The surface of the glass or porcelain is first roughened by the fumes of hydro-fluoric acid, and then varnished and black-leaded, to form an adhering and conducting surface for the metallic deposit.

One of the most delicate operations of the art of electrotyping is that of copying copper-plate engravings. A cast is first made from the plate by electro-chemical action, in the same manner as a mould is taken from a medal. In such a cast all the lines are in relief; it is requisite, therefore, to make a second deposit on that surface to obtain a fac-simile with the lines engraved. Nothing shews more clearly the beauty of the electrotype process than these transfers of copper-plate engravings. The finest lines are most faithfully copied, and it is impossible to distinguish a print taken from the electrotype from the proof impression of the original.

It was at one time expected that this mode of multiplying copper-plate engravings would supersede engraving on steel plates; but it has been found in practice, that the copper deposited does not possess sufficient hardness to resist the wear and tear of copper-plate printing. This objection may, however, be overcome; and there were displayed in the Great Exhibition sheets of copper deposited by electro-chemical decomposition, that appeared to possess the firmness of hammered plates.

A very successful application of electro-metallurgy to the fine arts is the process called glyphography. It consists in depositing on a plate of copper a design in relief, that may be printed from by the letter-press. The surface of the copper-plate is coated with wax, through which the design is cut sufficiently deep to expose the metal. This plate is then electrotyped, and copper is deposited in all the lines cut through the coating. By this means there is left on the plate, when the wax is removed, a perfect copy of the design in relief, so bold as to be printed from. This is, in fact, the original process invented by Mr. Spencer. The advantage it possesses over wood-engraving is in the facility of shading by "cross hatching," as it is termed, so as to resemble an etching on copper-plate.

The success or failure of the electrotype process depends very much on the preparation of the copper solution, and on the strength of the voltaic battery. A saturated solution is not so well adapted for the purpose, as such a solution diluted with one-fourth part of water. To prevent it from becoming too weak by the deposition of metallic copper, some crystals of the sulphate are added during the process.

Mr. Smee determined the laws that regulate the deposition of metals in different states. The strength of the battery, in relation to the strength of the solution, causes the metals to be deposited either as a black powder, in a crystalline form, or as a flexible plate. The metals are deposited as a black powder when the current of electricity is so strong that hydrogen is evolved from the medal or negative plate in the decomposition cell. The crystalline state occurs when there is no evolution of gas and no tendency thereto. The regular deposit takes place when the electric current is stronger in relation to the solution than in the last case, but is not sufficiently strong to cause the evolution of gas.

The art of electro-metallurgy has been more extensively practised in plating and gilding than in any other way. To appreciate the advantage of the process of electro-plating, it is requisite that the mode of manufacturing plated articles by the ordinary means should be understood. A thick plate of silver was attached to an ingot of copper, and the metals after being heated were passed through rollers, until they were reduced into a thin sheet of plated copper, the silver being equally spread over the surface. The plated copper was then cut into pieces, punched into the required forms, and soldered together; the interior being filled with melted lead. Such articles cannot be ornamented by engraving or chasing, but by milling and punching only. When the process of electro-plating is used, the articles may be cast, or put together in any convenient method, and the most elaborate designs may be worked in metal, which, on being afterwards coated with the purest silver, presents an appearance in every respect equal to the finest works in the solid metal.

The operations for electro-plating differ in several particulars from the ordinary process of the electrotype. The single-cell arrangement which has been described is inapplicable to the deposition of one metal upon another of a different kind. The plan of having a separate battery, with two or more combinations of plates, is indeed necessary even in the deposition of copper upon copper, when the operation is conducted on a large scale, and the electric current has to pass through a considerable resisting medium. When a separate battery is employed, the vessel in which the deposition is effected is called the decomposing trough.

To effect the deposition of silver or gold upon metals that are more easily oxidisable, a peculiar kind of menstruum is required; for if the silver be held in solution by an acid that will attack the baser metal, no electro-chemical deposition of metallic silver can be effected. The menstruum that is found most suitable for the purpose is a solution of cyanide of potassium. There are various modes of preparing the solution and dissolving the silver, but the cheapest and best, as recommended by Mr. Napier from practical experience, is to dissolve the silver in a solution of cyanide of potassium, by the action of a voltaic battery. The proportions mentioned are for operation on a large manufacturing scale, but the quantities may be reduced according to the requirements of the amateur. The

directions he gives are as follows: "Dissolve 123 ounces of cyanide of potassium in 100 gallons of water; get one or two flat porous vessels, and place them in this solution to within half an inch of the mouth, and fill them to the same height with the solution; in these porous vessels place small plates or sheets of iron or copper, and connect them with a zinc terminal of a battery; in the large solution place a sheet or sheets of silver connected with the copper terminal of the battery. This arrangement being made at night, and the power employed being two of Wollaston's batteries of five pairs of plates, the zincs seven inches square, it will be found in the morning that there will be dissolved from 60 to 80 ounces of silver from the sheets. The solution is now ready for use, and by observing that the articles to be plated have less surface than the silver plate forming the positive electrode for the first two days, the solution will then have the proper quantity of silver in it." The strength of the solution recommended is that of one ounce of silver to the gallon.

During the process of plating, the sheets of silver immersed in the solution gradually dissolve as the metal is deposited, and by this means the solution is maintained at the same strength.

In preparing articles for plating, they must be completely freed from grease by washing in an alkaline ley, and dipped into very diluted nitric acid to remove any traces of oxide. The object is then suspended in the decomposing trough and connected with the negative pole of the battery, the positive pole being connexion with a sheet of silver in the solution. Silver is immediately deposited, and the plating process proceeds as long as the object continues immersed. An ounce and a half of silver to one square foot of surface gives an excellent plating.

The articles when taken out of the solution are white, the silver being afterwards polished on the parts required to be bright. A bright deposit may, however, be made by adding a little sulphuret of carbon to the solution. When a thin coating of silver is deposited on a bright surface, the silver is also bright; and in order to obtain a coating of dead silver on a medal, it should have a thin film of copper deposited over its surface before it is immersed in the silver solution, by which means the silver, even when very thin, will be white.

In operating on a large scale, the decomposing trough is upwards of two yards long, one yard deep, and one yard wide, and contains about 250 gallons of the solution. At Messrs. Elkington's establishment at Birmingham, several of these troughs are in continual use. The silver plates in a single trough expose a surface of nearly thirty square feet, and the articles to be plated are suspended from metal rods that are connected with the positive pole of the battery. The voltaic batteries used by Messrs. Elkington generate large quantities of electricity of low intensity. When we inspected their manufactory, the deposition of each trough was effected by plates the zincs of which were three feet long by eighteen inches wide. Mr. Napier, however, recommends batteries with smaller plates, with several combined in a series, to increase the intensity of the electric current.

The operation of electro-gilding very closely resembles that of electro-plating. The gold solution may be prepared by dissolving gold in a solution of cyanide of potassium in the same manner as the silver, but the liquid should be heated. The strength of the gold solution need not ex-

ceed half an ounce of gold to the gallon, and a sufficiently thick coating of the metal is deposited in two or three minutes. Voltaic batteries of three or four pairs of plates are generally employed for electro-gilding; but if the solution be heated to nearly the boiling-point, a single pair will answer the purpose, for the hotter the solution the less the battery power required.

The method of gilding, before the introduction of the electro-chemical process, was extremely injurious to health. The gold was converted into a thin amalgam with mercury, which was brushed over the surface of the article to be gilt, and exposed to a strong heat to dissipate the mercury. The mercurial fumes produced the most pernicious effects, notwithstanding all the care taken to prevent them; so much so, indeed, that the average lives of the workmen engaged in gilding by mercury do not exceed thirty-five years. Electro-gilding is also prejudicial to health, though not to the same extent, and the operation should be conducted in a lofty well-ventilated room.

CHAPTER XXII.

ELECTRIC CLOCKS.

First application of electricity to indicate time—Bain's self-acting electric clock—Means of making and breaking contact—Application of mechanical power—The earth battery—Shepherd's electro-magnetic clock—Independence of the pendulum, and its advantages—Instantaneous indication of Greenwich time at distant places.

THE claim to the invention of electric clocks has been disputed by Professor Wheatstone and by Mr. Bain; but whatever claim Professor Wheatstone may have to be the original designer of such application of electric force, to Mr. Bain is unquestionably due the merit of having brought it into practical operation.

In 1841, Mr. Bain, in conjunction with Mr. Barwise, obtained a patent for the application of electricity to the regulation and movement of clocks. The invention at that time specified had for its principal object the movement of several clocks by currents of electricity, transmitted at regular intervals by the agency of a clock of the ordinary construction. The advantage proposed to be gained was, to make any number of clock-dials in a large establishment indicate exact time with one well-made clock, without requiring any impelling mechanical power. By a subsequent improvement of the invention, each clock was made to move independently by electricity, without any assisting clock to regulate the transmission of the electric current. The arrangement by which the independent regulated movement is obtained will be understood by the annexed figure.

The bob A of the pendulum A B consists of a hollow coil of covered copper wire. A hollow brass tube C C, about two inches in diameter, passes through the coil, there being sufficient space left for the coil to move to and fro without touching. Within the hollow tube, and on each side of it, are placed permanent bar magnets, with their similar poles presented

towards each other at a distance of about four inches apart. For example, the magnets within the tube on the right hand have their north poles presented to the coil, and those on the left hand have also their north poles presented to it. When an electric current passes through the coil it becomes instantly magnetic; the end towards the right, we will suppose, having a south polarity, and that towards the left a north polarity. The coil is consequently immediately attracted towards the right, and is repelled by the magnets on the left, as the pendulum swings in that direction. Before arriving at the end of its vibration, the connexion with the voltaic battery is broken by the action of the pendulum itself; the magnetic property of the coil instantly ceases, and it descends by the force of gravity. On ascending the other arc of its vibration, contact is again made with the battery, and the electric current is sent through the coil, but in the reverse direction; so that the left-hand end of the coil has south polarity given to it, and the right becomes the north pole. By this reversal of the current the coil is impelled towards the left, and the vibrations of the pendulum are thus maintained for an indefinite time.

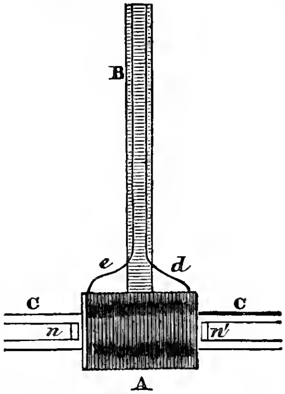


fig. 94.

To make and break contact with the wires of the voltaic battery, and to reverse the direction of the electric current, a light sliding frame is carried from side to side by the pendulum. The wires *e d*, from the opposite ends of the hollow coil, are carried up the pendulum-rod. A cross-piece of wood fixed to the clock-case serves as a stage whereon the light movable frame slides, the uprights whereon it rests being gold wires. Inlaid in the stage or cross-piece are studs of gold, connected by wires to the voltaic battery. When the pendulum vibrates towards the right, the movable frame is carried towards the right hand, so that two of the upright gold wires rest on the studs; by this means connexion is made with the voltaic battery, and an electric current is transmitted through the coil A. On the returning vibration of the pendulum the movable frame is shifted towards the left, and the electric current is reversed, the polarity of the coil being thus changed at each vibration of the pendulum.

In ordinary clocks the impelling power of a weight or spring communicates motion to a train of wheels, and the use of the pendulum is to retard and regulate the motion; but in Mr. Bain's electric clock the movement of the pendulum propels the hands, and the train of wheels is dispensed with. The mode by which the vibrations of the pendulum are applied to propel the hands will be readily understood on inspection of fig. 95.

An electro-magnet A is fixed on the top of the clock, and an electric current is sent through the coil on each vibration of the pendulum. Each time that the electro-magnet is put into action by these transmissions of electricity, the keeper B, to which the light-jointed click-lever D is attached, is attracted, and falls into a tooth of the ratchet wheel E. When the connexion with the battery is broken on the fall of the pendulum, the lever is forced back by the spring at B, and thus advances the wheel the space of

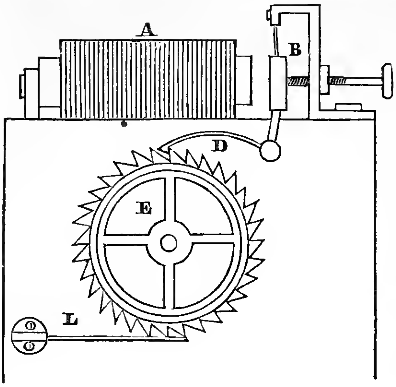


fig. 95.

one tooth. A small spring keeps the wheel steady, and prevents it turning back during the next vibration; and by this arrangement the ratchet-wheel is advanced one tooth by two swings of the pendulum. Thus, when the wheel contains thirty teeth, and the pendulum vibrates once a second, the wheel will make one complete revolution every minute. That wheel will therefore constitute the seconds wheel of the clock, and the minute and hour hands may be moved by it, in the same manner as in ordinary clocks.

The voltaic power employed by Mr. Bain in working these clocks consists of a large plate of zinc, and a quantity of coke buried in moist ground. Mr. Bain first directed attention to the use that may be made of the moisture of the earth in exciting a very steady current of voltaic electricity. In the earlier experiments he employed a large plate of zinc and a corresponding plate of copper; but it was afterwards found that coke or charcoal, among which copper wires were introduced to act as conductors, answered the purpose better, because a larger surface is thus exposed to contact with the moisture. On making connexion between the coke and the zinc a current of electricity is established, which, though of very feeble intensity, is sufficiently powerful to keep the pendulum of the electric clock in motion.

It was supposed by Mr. Bain that the electricity thus excited was derived directly from the earth, and he attached great importance to the discovery as a new source of obtaining electric power; but the effect is due only to the moisture of the earth acting on the zinc, and plates of equal size, if immersed in water, would generate an equal amount of electricity as when buried in the ground. In practice, however, there is considerable advantage gained by employing an "earth battery," for the action proceeds undisturbedly, and a battery of this kind will continue at work for a year or longer without requiring any attention.

Objection has been raised to Mr. Bain's clock, that as the pendulum is impelled by the direct action of electro-magnetism, it is liable to be affected by any variation in the power of the voltaic current, and such variations are continually taking place, even in the earth battery. The mode of making contact by the movable piece is also uncertain, and by a slight deposition of dust the connexion may be interrupted. With proper care, however, these clocks will continue to perform well for several months without touching them.

Mr. Shepherd, whose gigantic electric clock kept time over the central entrance of the Great Exhibition, has effected a considerable improvement by rendering the movement altogether independent of variations in the electric power. In his clocks the vibrations of the pendulum are maintained by repeated blows of a small spring, the electro-magnetic power

being employed only to draw back the spring after it has given the blow, so as to be ready to strike again when the pendulum returns. The regularity of the movement is still further secured by detaching the pendulum from the mechanism that propels the hands, which are moved forwards by separate electro-magnets. All that the pendulum does is to make and break contact with a voltaic battery by striking against a small spring at every vibration. The instant that contact is made, not only is the impelling spring drawn back by an electro-magnet, but other electro-magnets are brought into action alternately, and by their successive altractions propel the seconds-wheel of the clock. By this arrangement the isochronous motion of the pendulum is not interfered with by any variation in the power of the battery, nor by the attachment of mechanism of any kind.

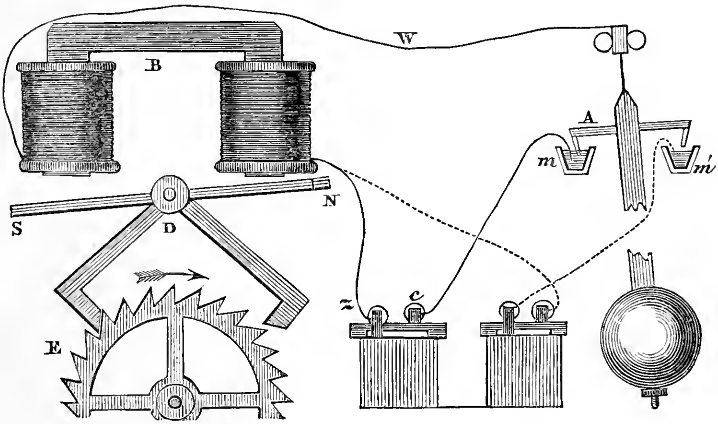


fig. 96.

Figure 96 shews Mr. Shepherd's arrangement for making and breaking contact with the voltaic batteries, and his mode of applying electro-magnetism to propel the mechanism of the clock. A metallic cross-bar A, fixed to the upper part of the pendulum, has two projecting pins of platinum, that dip alternately in cups of mercury *m m'*, as the pendulum vibrates. Wires are carried from each cup of mercury to a separate voltaic battery, and from the batteries to the electro-magnet B, and thence to the pendulum of the clock. A permanent magnet N S is fixed to the top of the palette D, which is so arranged in respect to the ratchet-wheel E, that it propels it one tooth at each double action. Thus, when the pendulum vibrates to the right, as shewn in the figure, connexion is made through the cup *m* with the battery *c z*, and the electro-magnet attracts the north pole N of the permanent magnet, and repels the south pole. The opposite action takes place when the current is reversed, by making connexion through the cup *m'*, and the other battery is brought into play. In this manner the alternate movements are continued, and the ratchet-wheel is regularly propelled.

A single pendulum will serve to move the hands on the dials of any number of clocks. Such an arrangement has been in operation for some

time at an extensive warehouse in the city. All the dials of a numerous series of clocks are regulated by one pendulum placed in the counting-house, and the wire required to communicate between the pendulum and the dials in different parts of the warehouse is upwards of a quarter of a mile in length. When several clocks are required in one establishment, great advantage is derived by employing electro-magnetism in this manner, because the dials of all indicate exactly the same time; they can be constructed at considerably less cost than good ordinary clocks, and they continue to go without the trouble of winding up. The public clocks of a whole town might thus be propelled, by employing a more powerful voltaic battery, the movements of all being regulated by a single pendulum.

In connexion with electric clocks may be mentioned the means of indicating exact time at different places. An arrangement of this kind has been recently completed between the Royal Observatory at Greenwich and the Electric Telegraph Company's office in the Strand. A large ball on the top of the Royal Observatory falls daily, to indicate exact, time at one o'clock, and a similar ball on the top of the Telegraph Office also falls at the same instant; communication being made between the two places by an insulated telegraph wire. The method by which the descent of the ball in the Strand is effected will be understood on inspection of figure 97. Let A represent a section of the tube on which the large hollow ball B slides up and down. A jointed lever E, consisting of a piece of soft iron, acts as the keeper of the electro-magnet M, and when resting perpendicularly, a projection on the other side takes hold of a catch D in the straight arm that is fixed to the ball, and thereby holds it in position at the top of the perpendicular tube. The instant that the ball on the Royal Observatory falls, it makes contact with a voltaic battery in connexion with the wires C Z of the electro-magnet M, and brings that magnet into action; the keeper E is attracted from the catch D, by which the ball is supported, and it thus falls at the same instant as the ball at the Observatory. To prevent concussion, by accelerated velocity during the descent, a plunger attached to the rod that supports the ball is introduced in the tube F, and by compressing the air within, the fall of the ball is sufficiently retarded.

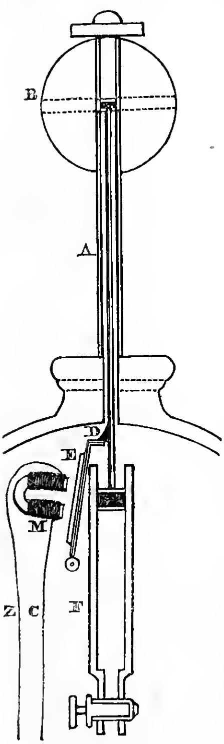


fig. 97.

The arrangements at the Observatory for liberating the ball exactly at one o'clock were effected by Mr. Shepherd in the following manner: Three small pairs of springs for making contact, *a*, *b*, *c*, are fixed on the frame of the clock, so that they may be pressed together by projecting pins *e*, *f*, *g*, on the wheels that carry the hour-hand, the minute-hand, and the seconds-hand respectively. The wire *z* connected with the voltaic battery is attached to the pair of springs *c*, and when they are pressed together by the pin *e*, metallic contact is made with the spring

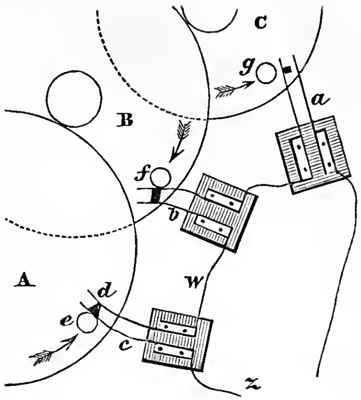


fig. 98.

b, by a connecting wire *w*. When these springs are pressed together by the pin on the wheel B, connexion with the battery is extended to the third pair of springs *a*, and on contact being made by the pin on the seconds-wheel C, the voltaic circuit is completed through the three springs, and the electric current puts in action an electro-magnet, which withdraws the detent that supports the ball on the top of the Royal Observatory.

It will be observed that to complete the circuit it is necessary that the three contact springs should be pressed together at the same time. As the hour-hand on the first wheel A, which revolves once in twenty-four hours, approaches towards one o'clock, it first presses together the spring *d*, and as that wheel moves slowly, contact is made for a quarter of an hour or more before the time required. The minute-wheel B next makes contact about half a minute before one o'clock, but no effect is produced until the seconds-wheel C makes contact exactly at one o'clock, and at that instant the voltaic current passes, first to the electro-magnet on the Observatory, and thence to the electro-magnet which liberates the ball on the Telegraph Office in the Strand. The balls are wound up by mechanism at half-past twelve o'clock. It is proposed to extend similar arrangements to different parts of the kingdom, through the telegraph wires; so that correct Greenwich time may be known once every day.

In the figure some of the wheels in the train of the clock are omitted to avoid confusion; but it is evident that by this arrangement the voltaic circuit can only be completed once during the revolution of the hour-wheel, however often contact is made with the springs connected with the other wheels.

CHAPTER XXIII.

MISCELLANEOUS APPLICATIONS OF ELECTRICITY.

The electric light—Electro-magnetic engines—Blasting rocks—Explosion of fire-damp in mines—Sounding the sea—Determining longitudes—Fire-alarms—Table-moving—Harpooning—Conclusion.

THE ELECTRIC LIGHT.

THE application of electricity to the purposes of illumination was brought prominently into notice about four years since, and then promised to become a most valuable means of lighting streets. The electric light proposed to be employed, though introduced as a new discovery, was

nothing more than the previously well-known evolution of brilliant luminous rays from charcoal points when exposed to the action of a powerful voltaic battery. The light thus produced almost equals in brilliancy and purity that of the sun; and if means could be found of regulating the action, so as to ensure steadiness and certainty, it would prove a most useful source of illumination.

Mr. Stait, when proposing to make the electric light available, invented a voltaic battery intended to act with great steadiness, and he introduced arrangements for adjusting the charcoal points, which improvements it was thought would overcome the difficulty; but though he succeeded in maintaining the light for a short time, it could not be regulated with the steadiness and certainty requisite for practical use.

An ingenious contrivance by Mr. Allman was in the Great Exhibition, of a self-acting adjustment of the charcoal points, so that the distance apart might vary in proportion to the variations in the power of the battery. We have not, however, heard of any practical application of this invention; and we fear it has not been found to overcome the difficulty.

Another objection to the application of the electric light, in an economical point of view, is the cost of generating the electric force. It has been ascertained by experiment that the expense of maintaining the requisite battery power would considerably exceed that of the quantity of gas that would yield an equivalent amount of light. This objection, though it might prevent the electric light from coming into general use, would not prevent its being applied in many cases where the question of cost is an inferior consideration, could the constancy of the light be depended on.

The impediment to the perfection of the invention, occasioned by the cost of exciting power, will probably be removed by the discovery of some better and cheaper means of exciting voltaic electricity than by the consumption of zinc; and in that case the electric light may become as common a source of artificial illumination as coal-gas is at the present day. Even in the imperfect state in which the invention now remains, the electric light might, with proper care and attention, be applied with great advantage to many lighthouses on the coast.

Some recent investigations, by Professor Wartmann of Geneva, into the applicability of the electric light, tend indeed to shew that it may be used to advantage more generally than we have, in the existing state of the invention and in the imperfect condition of the voltaic battery, assumed to be practicable.

It is asserted that the light emitted from a single pair of charcoal points equals that of 300 large burners; and that when a powerful voltaic circuit is formed, the charcoal points may be introduced at several parts of the circuit, and thus distribute the light from several points of illlumination.*

ELECTRO-MAGNETIC ENGINES.

The application of electro-magnetism as a moving power is, like the electric light, also awaiting, for practical purposes, further improvements in the mode of generating voltaic electricity.

Electro-magnetic engines of various kinds have been constructed, some

* Philosophical Magazine, January 1853.

of which have propelled boats and worked printing machines; but the amount of power obtained has been so small compared with the cost of the voltaic battery, as to render such applications of electricity practically useless as substitutes for steam. The most simple of the various modes by which electro-magnetism may be applied to propel machinery is shewn in the annexed diagram.

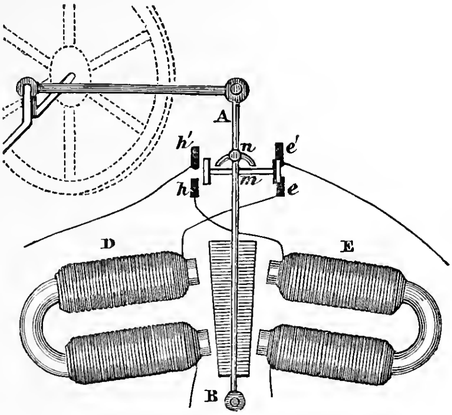


fig. 99.

The lever A B, jointed at B, is either made of soft iron or it has bars of soft iron fixed on each side to serve as keepers for the electro-magnets E D. The magnets are fixed in inclined positions, as shewn in the figure, so that the keepers on the movable lever may rest on the poles of each alternately, as it is attracted from side to side.

Two pairs of metal studs *e e'*, *h h'* are connected respectively with one end of the coils of the electro-magnets and with the voltaic battery that brings them into action. Thus, the wire of magnet D is connected with *e*, and a wire from the stud *e'* is connected with the battery. A movable piece of metal *m* slides laterally, and is shifted from side to side by the curved piece *n* striking against it when the lever A B is in action. When that sliding piece of metal rests upon either pair of studs, it completes the communication with the voltaic battery through the magnet to which the stud is connected.

In the position of the engine, represented in the figure, the sliding piece is resting against the stud connected with the electro-magnet D, which consequently becomes magnetic and attracts the lever. The instant before the keeper comes in contact with the magnet, the connexions are reversed, by the curved piece *n* shifting the sliding metal from its contact with *e e'* against the opposite studs; and by this means the magnet E comes into action, and the lever is attracted towards it. In this manner the lever may be kept in action for an indefinite time. The alternating movement may be converted into rotary motion by means of a crank, in the ordinary manner.

In some electro-magnetic engines rotary motion is communicated directly to a wheel, without the intervention of a crank, by fixing a number

of electro-magnets in the circle of rotation close to the periphery of the wheel, into which numerous pieces of soft iron are inlaid. Each electro-magnet is brought into action in succession by making and breaking contact with the voltaic battery as the wheel revolves; by this means there is a continuous change in the points of attraction round which the wheel is thus made to rotate.

One cause why so little power is obtained by electro-magnetic engines of these constructions is the limited sphere of electro-magnetic attraction. In the arrangement of the vibrating arm, for example, the force with which the keeper is attracted is very feeble until it approaches close to the magnet, when the magnetic action must necessarily cease. With a view to overcome this objection, an arrangement has been contrived in which the attractive power of a hollow coil is employed. A model engine of this kind was placed in the Great Exhibition. Its mode of action will be understood by the annexed section. Two hollow coils of covered copper

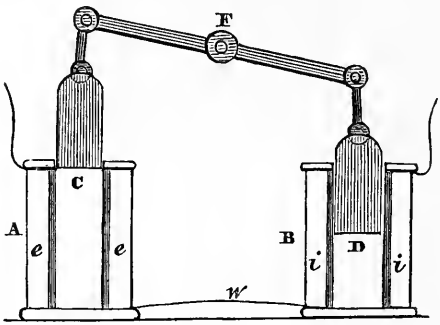
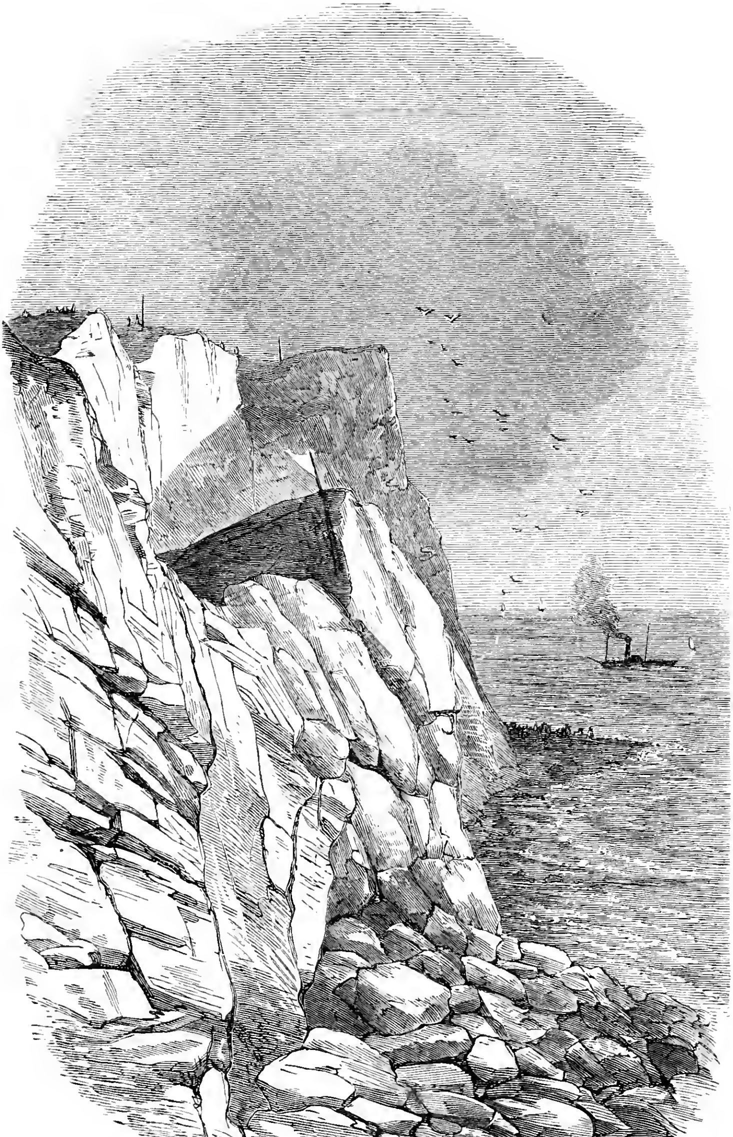


fig. 100.

wire A B are fixed vertically, the coils being connected together as if they formed the helices of an electro-magnet. Inside the coils two hollow cylinders of soft iron *ii* and *ee* are introduced. Two plungers C D, formed of soft iron, are mounted on a balance lever F. The ends of the coils are connected with the balance lever in such manner that as each end rises and falls alternately, it reverses the direction of the voltaic current through the coils in a manner similar to that shewn in fig. 99, and thus reverses the poles of magnetic attraction. In the position represented, the plunger D having reached the centre of the coil, where there is no magnetic action, the direction of the electric current is reversed by the lever, and C is then attracted into the hollow coil A. The lever is thus alternately lifted up and down like the beam of a steam-engine, the two hollow coils representing the two cylinders.

By this means of applying the force of induced magnetism the sphere of attraction is very much increased, especially when permanent steel magnets are used as plungers, for it then extends almost to the centre; and as the attractive power in one of the coils diminishes, the repelling power of the other is correspondingly increased. We have not heard of any practical application of this form of electro-magnetic engine; but it is a new mode of applying the force of electro-magnetism, which promises to be attended with favourable results.



p. 191.

ROUND DOWN CLIFF BLASTED BY ELECTRICITY.

In the Reports of the Juries of the Great Exhibition an electro-magnetic engine, invented by Mr. Hjorth of Denmark, is highly spoken of. It operates on the same principle as the engine we have just noticed. It consists of two sets of hollow horse-shoe electric magnets, conical inside, with a corresponding number of solid electro-magnets, which by mutually attracting each other, make a double stroke of four inches in length. The power has been found, by means of a spring-balance, to be about thirty pounds at the commencement of the stroke when the distance of the respective poles is about half an inch, decreasing slightly by degrees as the piston enters into the hollow electric magnet.* The Jury state, "we cannot help flattering ourselves that the attainment of this mysterious motive force will soon be followed by the making it available for practical purposes."

BLASTING ROCKS.

When a voltaic current is transmitted through a thick wire, it is conducted so freely that there is no sensible increase of heat. But if a very thin wire be interposed in the circuit, the resistance thus offered to the electric current causes the evolution of heat sufficient to make the wire red-hot. This heating property of the voltaic current has been rendered available in blasting rocks. Thick wires from a voltaic battery containing a series of plates of not less than four inches square are laid down to the spot where the explosion is to take place, and at that point the circuit of thick wire is broken, and a short length of very fine platinum wire is introduced. The fine wire is usually inserted in a cartridge of gunpowder, and it is covered over by the powder to be exploded. When every thing is properly arranged and all persons have retired to safe distances, the thick wires are connected with the two poles of the battery, and the powder is instantly ignited.

This plan of blasting rocks is more effectual and more free from danger than the ordinary method of igniting the powder by a fuse, for it sometimes happens that the lighted fuse communicates with the powder before the time calculated; occasionally also it hangs fire, and the men, supposing it to be extinguished, approach the mine and are killed by the unexpected explosion.

The application of voltaic electricity to the purposes of igniting large charges of powder was first successfully made by Col. Pasley in blowing up the wreck of the Royal George, and it has since been generally employed for submarine explosions. The most remarkable instance of this application of electricity was the removal of an immense mass of the Round Down Cliff at Dover, on the 26th of January, 1843. The cliff was 375 feet above high-water mark; and as a projection of it prevented a direct line of the South-Eastern Railway being taken to the mouth of the Shakespeare tunnel, it was resolved to remove the obstruction by blasting. Three different galleries and three shafts connected with them were excavated in the chalk rock. The length of the galleries was about 300 feet, and at the bottom of each shaft was a chamber eleven feet long, five feet high, and four feet six inches wide. In these chambers 18,000 pounds of gunpowder were placed in bags, with the mouths open and loose powder scattered over them. The distance of the charges from the face of the

* Reports of the Juries, class x. p. 283.

cliff was about seventy feet. At the back of the cliff a wooden shed was constructed in which three voltaic batteries were arranged. Each combined battery consisted of eighteen of Daniell's cells and two common batteries of twenty pairs of plates each. To these batteries were connected thick wires, covered with cord to insulate them from the ground. The wires were laid upon the grass to the top of the cliff, and then falling over it were carried to the eastern, the central, and the western chambers. The wires were each 1000 feet long, and it was ascertained by experiment that the electric current was sufficient to heat the interposed length of platina wire at a distance of 2300 feet. The powder was divided into three charges, each one being exploded separately by a distinct circuit, it being arranged that at the instant the central charge was fired, the voltaic current should also be transmitted through the two other circuits. Flags were fixed at various points on the cliffs to warn people not to approach, and on the top of the Round Down Cliff a larger flag was planted, towards which all eyes were directed as the time appointed for the explosion approached. "At twenty-six minutes past two o'clock," as reported in the *Times* of the following day, "a low, faint, indistinct, indescribable, moaning subterranean rumble was heard, and immediately afterwards the bottom of the cliff began to belly out, and then, almost simultaneously, about 500 feet in breadth of the summit began gradually but rapidly to sink. There was no roaring explosion, no bursting out of fire, no violent and crashing splitting of rocks, and, comparatively speaking, very little smoke; for a proceeding of mighty and irrepressible force, it had little or nothing of the appearance of force. The rock seemed as if it had exchanged its solid for a fluid nature, for it glided like a stream into the sea, which was at the distance of 100 yards, perhaps more, from its base." The top of the Round Down Cliff did not fall down on to the beach as might have been expected, but it descended almost perpendicularly, retaining its former distinctive character at a lower level than the surrounding cliffs which it before overtopped, as represented in the accompanying engraving. By this blast one million tons of chalk were removed, which would have otherwise required twelve months' labour to cut away.

EXPLOSION OF FIRE-DAMP IN MINES.

The same arrangement that is adopted for blasting rocks might be applied, with great effect, to diminish the loss of life occasioned by explosions of carburetted hydrogen gas in coal-mines. It is the practice in many mines that are considered to be "fiery," for a man to descend every morning, before the miners go to work, to ascertain whether the passages are in a safe condition. The duty of the "viewer" is to proceed to all the dangerous parts with a safety-lamp, and if he finds from the indications of the flame within the wire gauze that the atmosphere is inflammable, the miners are not allowed to descend until additional means have been taken to ventilate the mine. This duty is sometimes very negligently performed, and in the case of a fatal explosion which occurred last summer, several of the miners accompanied the viewer with unprotected candles, and most of them were killed.

The trouble and loss of time of this precautionary examination and its accompanying danger might, the author conceives, be saved, by igniting lucifer-matches, or other combustibles, by voltaic electricity in various

parts of the mine. This might readily be done at a very trifling cost. A thick insulated wire fixed to the side of the shaft from the mouth of the pit to the farthest part of the workings, and there attached to a copper plate immersed in a pool of water, would serve to conduct the current of electricity, and the return current might be completed by a similar plate of metal buried a few feet deep in the moist earth near to the battery at the pit's mouth. By intercepting the thick wire circuit in those parts usually most dangerous, and introducing a short piece of very fine platina wire, heat sufficient would be evolved at those points, when the circuit was completed through the battery, to ignite lucifer-matches laid upon the fine wires over night. By this means the condition of the mine could be ascertained in an instant, without personal examination.

There would of course be objections raised to any plan so different from the usual routine, but in the opinion of the author it presents an easy, safe, and practicable mode of testing the safety of coal-mines, which it would be advisable, at all events, to try.

SOUNDING THE SEA.

In sounding the sea by "the lead" at great depths, it is difficult to ascertain exactly when the weight strikes the ground. An ingenious contrivance has been invented by Mr. Bain for removing the difficulty by employing electrical agency. We are not aware that the invention has yet been brought into use; but it may be desirable to explain the *modus operandi* as an illustration of one of the many different ways in which electricity may be applied.

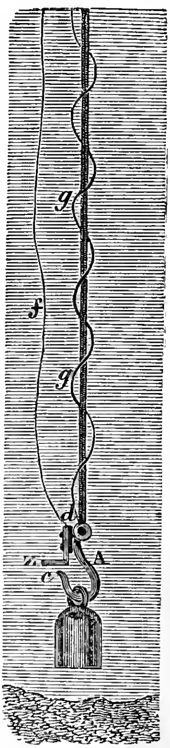


fig. 101.

In fig. 101, A represents a metal spring-hook, the curved end of which *c* presses against the projection Z, when the two points are not kept apart by the weight of the lead, as they are represented to be in the woodcut. The end *c* is insulated from the other part of the hook by the piece of wood *d*. A wire *g*, connected with the end *c*, proceeds from one of the coils of an electro-magnet on the deck of the ship; the wire *f* proceeds from a voltaic battery to which the other end of the coil of the electro-magnet is attached. By this arrangement it will be perceived that when the points *z* and *c* come in contact, the electro-magnet will become active; and the keeper, as it is attracted, may strike a bell, or give notice in any other convenient way. This would take place as soon as the lead touched the ground, for its weight would then cease to operate against the action of the spring in keeping the two ends apart; and by this means the instant that the bottom was reached would be made known.

For the sake of shewing the action more clearly the two wires are represented in the figure as entirely separated; but they might be both twisted together round the plumb-line, if care be taken to insulate them from each other by a covering of cotton well varnished.

DETERMINING LONGITUDES.

Instantaneous communication from place to place, by means of electricity, has been applied to determine the longitude. This was first done in America at great distances apart, and recently in this country; Professor Challis, of Cambridge observatory, having in May last undertaken a series of experiments, in connexion with the Royal Observatory at Greenwich, for that purpose. The principle on which this application of electric force depends is very simple. A telegraphic wire was connected with the observatory at each place, and the instant that the seconds-hand of the clock at Greenwich indicated a given time, a signal was transmitted through the telegraph-wire, and the Cambridge time was directly noted. The difference between the two affords the means of determining the longitude with great exactness, by shewing how much sooner the sun comes to the meridian at Cambridge than at Greenwich.

FIRE ALARMS.

Electro-magnetism has been ingeniously applied to sound an alarum in case of fire. The action of the instrument depends on the well-known expansion of mercury by heat. The mercury is contained in a glass bulb similar to the bulb of a thermometer; and when heated it rises up the tube and touches a wire which is connected with a voltaic battery, and instantly brings into action an electro-magnet. A detent is then withdrawn from a piece of clock-mechanism, and an alarm is thus sounded whenever the room in which the thermometer-instrument is placed becomes heated a few degrees above the ordinary temperature.

In the accompanying figure A represents the glass bulb; B C are two short tubes communicating with it, into which wires are introduced. The bulb is filled with mercury, and placed in a vertical position, so that when it is expanded by heat it will rise up in the tube and touch the wire. The wire at the bottom is connected with the electro-magnet, and that at the top with the voltaic battery; and in this manner the circuit is completed as soon as the mercury becomes sufficiently expanded to rise as high as the wire C.

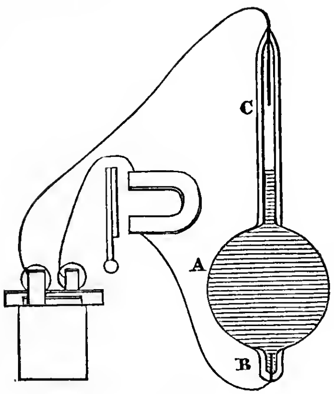


fig. 102.

A thermo-electric alarm might at very trifling cost be placed in every room of a house, one voltaic battery and one loud alarum being sufficient for all. In hotels, and in all large establishments, an apparatus of this kind would prove a great safeguard, as it would be the means of giving warning of danger before any indication of fire was otherwise perceptible.

TABLE-MOVING.

As the alleged phenomena of table-moving, which at present attract much attention, have been generally attributed to electrical agency, it

might be considered an omission in this work if the subject were not noticed. We have no hesitation in asserting, that it is absolutely impossible such effects could be produced by the known properties of electricity. Even admitting—which we are far from being inclined to do—that electricity can be excited by the imposition of hands, and that it could be so excited with unlimited abundance, no acccumulation of electrical force could operate in such a manner on a solid table placed upon the floor.

Let us consider for a moment the physical circumstances necessary to produce the simplest of the movements stated to occur. To raise a table on one side a few inches from the ground by electrical attraction would, in the first place, require a greater amount of electric force than was ever generated by the most powerful artificial means. Such a concentration of electricity could not fail to exhibit itself by the emission of sparks, by the attraction of all surrounding movable objects, and by the repulsion of any light bodies placed upon the table. No such effects are represented to be exhibited; and we are told that tables move without any previous manifestation of the ordinary phenomena of electrical attraction. It is also irreconcilable with all the known actions of static electricity, to suppose that it could be accumulated in quantity and intensity on such an imperfect insulator as a carpet. Even if that were possible, the attraction of the floor, as the nearer object, would greatly surpass that of the ceiling, and would therefore hold the table more firmly to the ground, instead of lifting it up.

If, again, voltaic electricity be the assumed agent, the difficulties are no less insurmountable. Attractive power in that case could only be obtained by inducing magnetism. We must suppose, therefore, the existence of some undiscovered property, which can impart an unknown kind of magnetism to wood, that is capable of attracting other similar bodies. But even admitting all this, a cause would still be wanting to account for the magnetised table being attracted to the more distant ceiling instead of to the floor.

We have only considered the causes necessary to account for the mere raising of a table on one side; and if the known properties of electricity are unable to produce that simple effect, they would be still less adequate to cause movements at the will of the operators, which, even though endowed with vitality and intelligence, a rigid table could not accomplish without assistance.

In addition to those inventions we have described, there are numerous other applications of electricity; some of which, however, are of little practical utility, and in other cases the practicability of the applications of the force is too questionable to render it requisite to give special descriptions. Among the variety of objects to which electricity has been applied may be mentioned a means of measuring the velocity of cannon-balls, and of other rapidly moving bodies; a mode of performing on musical instruments; the detection of the frauds of omnibus-conductors; and a plan for catching whales. The last-named invention we have only recently seen noticed, and if feasible, it will certainly afford great advantage to the arctic fishermen. The harpoon is connected by a wire to a voltaic battery, and the instant it strikes a whale it is to communicate a stunning shock that will render the creature powerless.

It is impossible to conceive limits to the extent to which electric force may be applied by the ingenuity of man as progress continues to be made in the science, and especially when more facile methods of generating electricity are discovered. Its importance as a means of transmitting intelligence is becoming daily more appreciated; and when the electric telegraph has received the improvements of which it is already capable, it will become a general means of correspondence. The other object to which we look forward at present as most likely to effect important changes in the social condition of mankind is, the application of electricity as a moving power. The practical part of the science is not yet sufficiently advanced to enable us to expect an early approach of this event; but we feel assured that not many years will have passed before means will be found of employing electric force with great advantage for that purpose; and when that time arrives, changes will be effected in the means and facilities of locomotion, as great as any that have been introduced by the power of steam.

INDEX.

LONDON:
PRINTED BY LEVEY, ROBSON, AND FRANKLYN,
Great New Street and Fetter Lane.